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EXPERIMENTAL SCIENCE

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NEW YORK . BOSTON . CHICAGO
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EXPERIMENTAL SCIENCE

AN ELEMENTARY COURSE OF PHYSICS AND CHEMISTRY

BY

Arman

SIR RICHARD GREGORY, 1864-

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MACMILLAN AND CO., LIMITED
ST. MARTIN'S STREET, LONDON

1920

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First Edition, 1899.
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Chemistry
Sotheran
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20 Jan. 15. E.H.W.

PREFACE

This volume provides a course of elementary physics and chemistry suitable for pupils in secondary schools who are preparing for public examinations of Junior School standard. The subjects included are treated, it is believed, with sufficient fulness to enable the young student to understand their true significance.

Attention is invited to the prominence given to experimental work throughout the book. The experiments are not only numerous, but can all be performed with very simple apparatus; in fact, the volume is intended to be as much a laboratory manual covering the rudiments of physics and chemistry as a class text-book. The plan adopted is to give instructions for experiments illustrating a given principle, and then to deal, in the descriptive text which follows the experimental work, with the general facts bearing upon it. A little repetition is thus unavoidable; but every teacher knows this is a merit rather than a defect in a book designed for beginners.

There is little scope for originality in a book of this kind, and the only claim in this direction which the authors wish to be considered is the plan of construction already described. In some of the chemistry chapters free use has been made of "Elementary General Science" (Macmillan), and the authors desire to express their thanks to Mr. L. M. Jones, B.Sc., one of the writers of that book, for permission to do this.

R. A. G.
A. T. S.

CONTENTS

CHAPTER I

PAGE
FORMS OF MATTER 1

CHAPTER II

MEASUREMENT OF SPACE 20

CHAPTER III

MASS AND WEIGHT 39

CHAPTER IV

DENSITY AND ITS MEASUREMENT 52

CHAPTER V

MEASUREMENT OF TIME, VELOCITY, AND ANGLES 73

CHAPTER VI

INERTIA AND FORCE 85

CHAPTER VII

THE LEVER AND PARALLEL FORCES 99

CHAPTER VIII

PRINCIPLES OF THE PULLEY, THE INCLINED PLANE, AND THE SCREW 117

CHAPTER IX

CENTRE OF GRAVITY 131

CHAPTER X

PAGE
WORK AND ENERGY 142

CHAPTER XI

EFFECTS OF HEAT. THERMOMETERS 156

CHAPTER XII

HEAT AND TEMPERATURE 173

CHAPTER XIII

CHANGE OF STATE IN RELATION TO HEAT 185

CHAPTER XIV

TRANSFERENCE OF HEAT 204

CHAPTER XV

REFLECTION AND REFRACTION OF RADIATION 215

CHAPTER XVI

DISPERSION AND THE ANALYSIS OF LIGHT 242

CHAPTER XVII

AIR AND ITS CONSTITUENTS 252

CHAPTER XVIII

WATER AND HYDROGEN 274

CHAPTER XIX

CARBON AND SOME OF ITS COMPOUNDS 293

CHAPTER XX

SOME FAMILIAR SUBSTANCES 303

CHAPTER XXI

TERRESTRIAL MAGNETISM 311

INDEX 337

EXPERIMENTAL SCIENCE

CHAPTER I

FORMS OF MATTER

What is meant by "Matter."—Our earliest knowledge of the world teaches us that on every side we have what we familiarly speak of as *things* of all kinds. We become aware of the existence of these things in different ways. Some we feel, some we smell, some we see, some we taste, while others again make their existence known to us by the sounds we hear. On a windy day at the sea-side, standing on the beach, we feel the ground under our feet ; we smell, it may be, the tar on a neighbouring boat or the seaweed on the shingle ; we see a distant ship at sea or the clouds hurrying across the sky ; we taste the salt in the air ; and we hear the never-ceasing roar of the waves as they break at our feet. All these things, about which we get to know by our senses, are called *material* things ; they are forms of *matter*. We must think of **matter,** then, as meaning **all things which exist in or out of our world, which we can become aware of by the help of our senses.**

The Senses.— The five ways of gaining information about matter, viz., seeing, feeling, hearing, smelling, and tasting, are sometimes called the **gateways of knowledge.** All facts of science are learnt by the help of the senses. It cannot be learned too soon that there is no difference between ordinary knowledge and science. To study science successfully one or more of the five senses are employed accurately, which is possible only after they have been carefully trained. Anything learnt by using the senses properly, without mistakes, is a fact of science. Or, as Huxley once said, "Science is organised common sense."

Different kinds of Matter.—Of course the number of different kinds of things is innumerable, but yet they can all be arranged in three classes, according to certain of the properties they possess, and which we shall immediately have to study. The classes are :—

(1) Solid things or solids ;
(2) Liquid things or liquids ;
(3) Gaseous things or gases.

Sometimes the last two are made into one class and called fluids.

Characters of Solids.

EXPERIMENTAL WORK.

1. *The Shape of a Solid does not Alter of Itself.*—Examine a variety of solid things. Notice they are of different shapes and that the shapes and volumes do not alter.

A solid offers resistance to force tending to change its form or bulk in any way. The property in virtue of which a body requires force to change its bulk or shape is called *elasticity.*

The following experiments show that elasticity may be called into play in solids by forces tending to stretch, bend, or twist them.

2. *Elasticity produced by Pulling.*—Clamp one end of a piece of thin india-rubber cord, about ten inches long, in a retort stand, or suspend it in any other convenient way. Clamp a wire or a strip of wood about the same length with it, so that the lower end is a little above the lower end of the cord. Tie a loop of strong thread to the bottom of the cord, and hang from it a light tray (Fig. 1). Push a pin through the cord so that it is level with the bottom of the wire or wood.

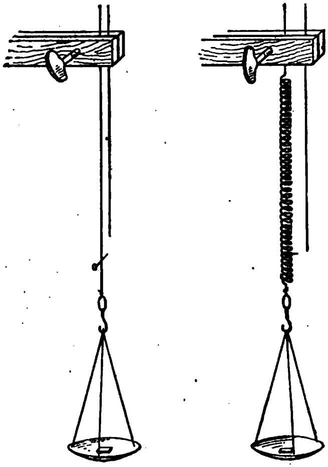


FIG. 1.—Elasticity produced by a pulling force.

Place a weight in the tray and measure the elongation produced by it, that is, measure the distance between the pin and the bottom of the wire or wood. Place another weight in the tray, and again notice the extension produced. In the same way find the extension produced by other loads. Then remove the load and notice that the india-rubber does not exactly return to its original length. Repeat the experiment, using a spiral spring instead of an india-rubber cord. In this case, the spring will return to its original length after being stretched.

3. *Elasticity produced by Bending.*—Procure a flexible wooden lath, and fix it horizontally by clamping one end of it firmly. To the other end attach a pin by means of a little wax. Place a rule vertically near the pin, as in Fig. 2. A weight should then be hung from the free end of the lath, and the amount of bending observed. Keeping the same weight, clamp the lath so that only half the previous length can be bent, and again notice the amount of bending. Try also with other lengths.

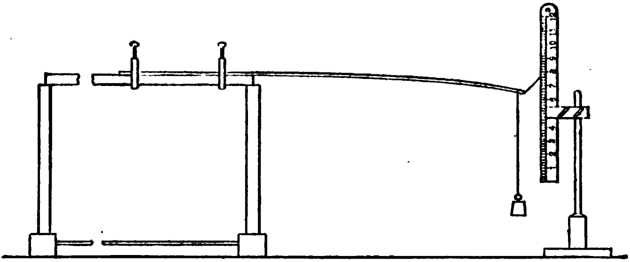


FIG. 2.—Measurement of the Bending of a Lath, or of Elasticity of Flexure.

4. *Elasticity produced by Twisting.*—Suspend a wire with a weight at its lower end, and under it a circle divided into degrees in a manner similar to that shown in Fig. 3. Notice the position at which the weight comes to rest; then twist the weight through a certain angle, and let it go. The weight untwists back to the starting point and beyond it, and then spins in

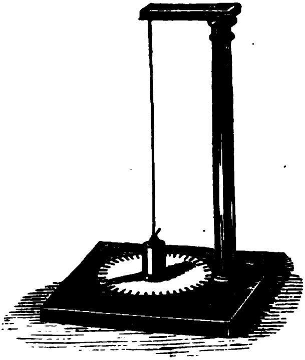


FIG. 3.—Elasticity of Torsion.

the way it was twisted, and goes on oscillating in this manner until it comes to rest. Observe how long the weight takes to make ten or fifteen complete spins. Repeat the observation with wires of different length and diameter, and made of different metals. The time of an oscillation depends upon the tendency to untwist, so that the experiment shows that this depends, among other things, upon the length, diameter, and nature of a wire.

Among the other properties which distinguish solids, *Tenacity*, *Ductility*, and *Hardness* may be mentioned. What is meant by each of these terms is made clear by the following simple experiments:—

5. *Tenacity.*—Suspend a balance-pan from the lower end of a thin copper wire attached to a beam. Add weights to the pan until the wire breaks. The force required to break the wire depends upon its tenacity, and is measured by the joint weight of the balance-pan and the weights in it. Repeat the experiment with wires of the same diameter but made of different material.

6. *Ductility.*—Procure a draw-plate. File one end of a piece of copper wire, which is larger than a given hole in the plate, so that you can just push the end through the hole you have chosen. Hold the protruding end by square-nosed pliers and convince yourself that by pulling you can draw the wire through the plate. Owing to its ductility the wire is permanently thinner than before.

7. *Hardness.*—Make a small collection of available solids; *e.g.*, flint, glass, steel knife, copper (penny), lead, chalk, and wax.

Select one of the things, and notice that it will scratch some substances but not others. Test the things which the knife will scratch or cut and the things it will not cut. Test in the same way the things the finger-nail will scratch and those it will not scratch.

Arrange the substances in pairs as below, so that one is scratched by the other. In this way a continuous table in which the substances are arranged according to their hardness can be drawn up thus:—

Flint scratches glass.
Glass ,, iron.
Iron ,, copper.
Copper scratches lead.
Lead ,, chalk.
Chalk ,, wax.

Solids.—Most of the things you see around you have a certain size and shape of their own. The table in front of you and the desk you sit on have the same shape now as when they were first brought into the school, if no one has done anything to them. In the same way, a stone, a brick, a piece of india-rubber, or a tumbler keep their own shape unless some one breaks them. Things of this kind, which have a size and shape of their own, and remain of the same size and shape so long as they are not interfered with, are called **solids**. Some solids are harder than others, and some can have their shape altered more easily than others. But none of them change by themselves. You know this very well in your own mind, though you may not have thought much about it. If you place a tumbler upon a table, and leave it for a while, you expect to find it there when you come back, and not changed into a bottle, because you know the shapes of solids do not alter unless some one alters them.

Using more precise language, it may be stated that **a solid body does not readily alter its size or shape. It will keep its own volume and the same form unless subjected to a considerable force.** Another way of expressing the chief facts contained in this definition is to say that *solids possess rigidity.* Hard solids are more rigid than soft ones. Liquids, on the other hand, possess no rigidity, but the opposite property of flowing or *fluidity.* Liquid particles slide over one another so easily that the surface of a liquid at rest is always horizontal. Fine sand may be made to flow, but the particles, however, do not move freely over one another, so the surface is left uneven, which fact provides us with a clear means of distinguishing between a solid and a liquid.

Distinctive Characters of Solids.—Different solids possess certain qualities, characters, or properties in varying degrees. Among the chief properties which distinguish solids from other forms of matter, **Rigidity, Tenacity, Ductility** and **Hardness** may be mentioned. The careful study of these and other properties belongs to the science called **Physics**; in an introduction to the study of science the simplest explanation of each of the terms will suffice.

Elasticity is the tendency of matter to go back to its original form or volume after being forced out of it. The capacity of a body to resist change of form or distortion is called rigidity. Elasticity can be called into play in solids, liquids, and gases by pressure; but only solids offer resistance to pulling, bending and twisting. A solid will only resume its original size when the force causing distortion is removed, provided that the force does not exceed a certain amount. If the force be greater than this particular value, or if it exceeds the *limit of elasticity*, as it is called, the solid will not return to the initial size; it will either break or undergo a permanent change of shape.

Tenacity is measured by ascertaining what weight is necessary to break solids when in the form of wires. The force required to tear asunder the particles of a body varies with different materials, in other words, some substances are more tenacious than others. It is found that a wire twice as thick as another will be just twice as tenacious. Evidently, then, if we wish to compare the tenacity of two wires of different materials, it will make the experiment much simpler if wires of the same cross section are selected. Cast steel is the most tenacious of all metals, being about twice as much so as copper and forty times as tenacious as lead. But the tenacity of steel itself is exceeded by that of unspun silk, while single fibres of cotton can support millions of times their own weight without breaking.

Ductility is the property by virtue of which solids can be made into wires. A ductile material is thus one which can be drawn out. The change of form in this case is produced by pulling. *Malleability* is a similar property to ductility, but the change of form is brought about by the application of pressure; gold, copper, and lead, for instance, can be beaten out into thin plates, and are therefore malleable substances. Lead is an example of a malleable material which is not ductile—it can be beaten out but cannot be drawn into wires.

Platinum is the most ductile and gold the most malleable metal known. Platinum has been drawn out into wire so fine that a mile of it weighs only one and a quarter grains. Gold has been beaten into plates so thin that it would require three hundred thousand of them placed one above the other to make a layer an inch thick.

Hardness is the property by virtue of which solids offer resistance to being scratched or worn by others. This is a property of great importance in the study of minerals, as it often affords a ready means of distinguishing them. The method of measuring hardness consists in selecting a series of solids, each one of the series being harder than the one above it, and softer than the one below it. At one end of the series, therefore, the hardest solid known is placed; at the other end, the softest which we may wish to measure.

Characters of Liquids.

EXPERIMENTAL WORK.

8. *Liquids take the Shape of the Containing Vessel.*—Show by pouring the same amount of water or other liquid into different vessels that the shape of the water depends upon the shape of the vessel.

9. *Flow of Liquids.*—Procure specimens of treacle and pitch. Soften the latter. Compare the consistency of the treacle and the softened pitch with that of water, and note the gradual increase in the viscosity of the liquids.

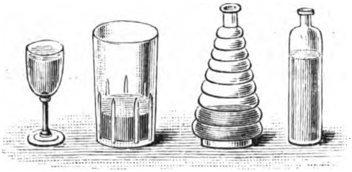


FIG. 4.—The shape of the liquid in these vessels is different, but the amount of liquid is the same, and the surface is horizontal in each.

10. *The Surface of Liquids at Rest is Horizontal.*—Into a shallow glass vessel pour enough mercury to cover the bottom. Attach a ball of lead to the end of a fine string, and so construct a *plumb-line.* Hang it over the surface of the mercury, and notice that the line and its reflection are in one and the same line. If this were not the case, that is, if the image slanted away from the plumb-line itself, we should know the surface of the liquid was not horizontal.

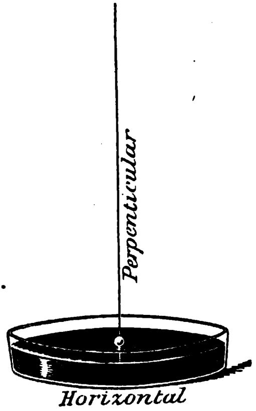


FIG. 5.—A perpendicular line, and the horizontal surface of a liquid.

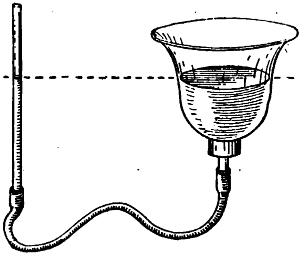


FIG. 6.—Liquids find their own level when they are free to flow.

11. *Liquids in Communication find their own Level.*—Connect the neck of a large funnel and the end of a glass tube (a burette or pipette) by means of a piece of india-rubber tubing. Or, connect a narrow tube

with the top of a glass table filter, the carbon of which has been taken out, as in Fig. 6. Pour water into the larger vessel and observe the level of the liquid in the narrow tube. Vary the height of the narrow tube, and notice that the level of the water in the large vessel and tube remains the same.

12. *Liquids communicate Pressure equally in all Directions.*—Make a hole in an india-rubber ball. Fill the ball with water by holding it under water and squeezing the air out. Prick a number of small holes in the ball by means of a long pin. Place a finger over the large hole and squeeze the ball; the water will spurt out of each hole straight from the centre of the ball, thus showing that the pressure has been transmitted in all directions (Fig. 7).

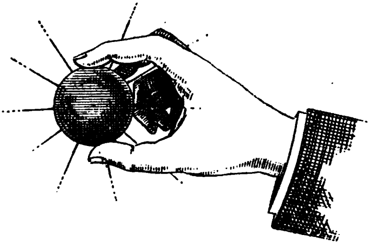


FIG. 7.—Liquids transmit pressure equally in all directions.

13. *Liquids can be Separated into Drops.*—(*a*) Sprinkle some powdered resin on a board and then a little water. Notice the water collects in *drops;* the smaller they are, the more nearly spherical they are. Observe the same thing with mercury on a sheet of paper.

(*b*) Mix methylated spirit and water until a few drops of oil just float when the mixture is quite cool. Pour fresh oil, by means of a pipette, into the middle of the mixture. Notice spherical globes of oil can thus be formed.

(*c*) Observe that drops once formed can be made to run together again by coming in contact.

The formation of drops is due to the cohesion of the liquid.

14. *The nature of cohesion is seen from the following easy experiment.*—Carefully clean and polish two pieces of plate glass, and then place one on the other. The two surfaces will be found to *cohere*, and considerable force will be required to separate them. Compare with the *adhesion* of a postage stamp to a letter.

Liquids.—If you put a stone into a tea-cup, then into a tumbler, and then into a basin, you know that the size and shape of the stone remain the same in all the vessels. This is also true of any solid. But if a certain amount of water, say a wineglassful, is taken and poured into a tumbler, you know that the water will not keep the same shape that it had at first. The water could be poured successively into vessels of different sizes and shapes, and finally into the wine-glass again ; but though *the shape would keep on altering*, being in every case the shape of the containing vessel, *the size would remain unaltered.* Things which behave in this way are called **liquids.** You can think of many liquids in use day by day. For instance, vinegar, oil, milk, beer, and lemonade are all liquids.

These facts can be expressed in the form of a definition, thus, —**A liquid at rest takes the shape of the lowest part of the vessel containing it, and has a horizontal surface; but the conditions remaining the same, it keeps its own size or volume, however much its shape may vary.** *When it is not held by the sides of a vessel it at once flows.* This is the commonest everyday experience. You cannot get a pint of milk into a glass of half a pint capacity. It does not matter what the shape of the bottle or jug may be—providing it holds a pint, as we say, or provided its capacity is a pint, the quantity of milk taken to exactly fill it is always the same. If you turn the jug upside down, the milk all runs away because there is no part of the vessel to prevent it from *flowing*.

The Flow of Liquids.—The power of flowing is not perfect in liquids. The small particles making up the liquid always stick to one another a little, and when any part of a mass of liquid moves, it always attempts to drag the neighbouring particle, which is at rest, with it. We can sum this up by saying that liquids would flow perfectly if they possessed no *viscosity.* Those liquids which have little viscosity, or, what is the same thing, are very *mobile* liquids, are instanced by alcohol and water ; while treacle and tar have little *mobility*, but are very *viscous.* Evidently, then, there is a gradation in those forms of matter which have as yet come before our notice. At one end we have very mobile liquids, which as the viscosity increases flow less and less easily, until at last there is no power of flowing at all, and we have the solid form of matter.

Liquids find their Level.—If several vessels of the most varied shapes (Fig. 8) are in communication with one another, and water be poured into any one of them, we shall find that as soon as the water has come to rest it will stand at the same level in all the tubes, however different the form of the vessels may be. It is this property of liquids which is utilised in the construction of the *water-level.* Its construction and use will be easily understood by a glance at Fig. 9.

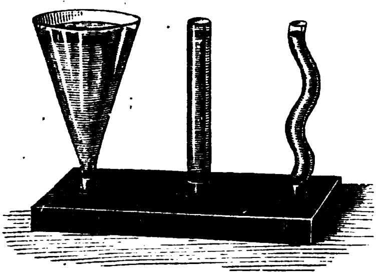


FIG. 8.—Vessels of various shapes in communication. Water standing at same level in all.

Liquids communicate Pressure equally in all Directions.—If we use a device after the pattern of the illustration Fig. 10, and fill it with water, when the piston working in the cylinder is pushed down the jets spurt out equally in all directions from the holes in the globe, thus showing that the pressure is communicated *equally in all directions.*

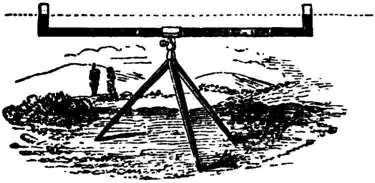


FIG. 9.—A Water-level.

Liquids can be Separated into Drops which will run together again.—Liquids are able to form drops because of a property, known as *cohesion*, which they possess. The larger the drop which can be formed the greater is the cohesion between the particles of the liquid.

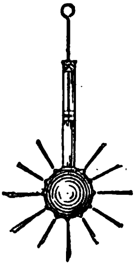


FIG. 10.—Equality of Liquid Pressure.

Cohesion is the mutual attraction which the molecules of a body exert upon one another; it is, indeed, the force which keeps the particles of a substance together. Cohesion is strongest in solids, which in its absence would crumble into powder; it acts between the particles of liquids, but in gases it may be said to be absent.

It will be as well before leaving this subject to learn in what way cohesion differs from another similar property possessed by some kinds of matter and which is known as *adhesion.* Adhesion denotes the attraction between unlike particles of matter. A metal plate may be made to *adhere* to glass ; and a postage stamp may be said to exhibit the existence of the force of adhesion when it is stuck upon an envelope.

Characters of Gases.

EXPERIMENTAL WORK.

15. *A Gas has no Surface and spreads itself through as much Space as it can.*—Collect a bottle of ordinary gas in the following way. Fill a bottle with water, and invert it in a basin of water; then displace the liquid with gas led from a jet by a piece of india-rubber tubing (Fig. 11).

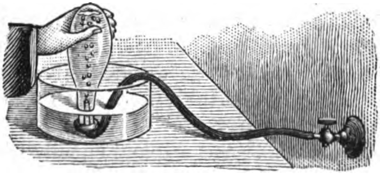


FIG. 11.—How to collect gas in a bottle.

Now insert a cork into the neck of the bottle while it is still under water, or cover the mouth with a glass plate, and lift the bottle out of the water and place it on the table. The gas has the size and shape of the bottle.

Open the bottle and wave it about; you immediately notice the smell of gas throughout the room, and know from this that the gas is everywhere in the room, and therefore has the size and shape of the room.

16. *Gases are easily Compressible.*—Place your finger over the nozzle of a penny squirt. Notice that by exerting force you can compress the air in the cylinder into a smaller space. Consider also the inflation of a bicycle tyre.

Gases.—It has already been explained that the leading difference between a solid and a liquid is the power of flowing which the latter possesses. Gases also possess fluidity, and to a much more marked degree than liquids. Liquids and gases are in fact both classified as **fluids.** But whereas liquids are almost incompressible, gases are very easily compressed into a much smaller space according to a definite law, viz., just in that proportion in which you *increase* the pressure on a gas do you *decrease* the volume which it occupies.

In the case of both liquids and gases, when the pressure is removed the original size is at once regained owing to the perfect elasticity of both these forms of matter. But *while solids show elasticity when acted upon by any force, liquids and gases only show it when compressed.*

A liquid always adapts itself to the shape of the containing vessel, and presents a level surface at the top ; a gas, on the other hand, will, however small its volume, immediately spread out and do its best to fill the vessel, however large ; and it does not present any surface to the surrounding air. We can never say exactly where the gas leaves off and the air begins. Another distinction will be more fully appreciated after we have considered the action of heat upon the volume of bodies. We shall learn that, generally speaking, all bodies get larger as they are heated ; this is very much more decidedly the case with gases than with liquids. **Gases** then, **are easily compressible and expand indefinitely.**

We shall learn that all gases expand equally when heated to the same extent, but this fact and others will be much better understood in their proper places.

Change of State.

EXPERIMENTAL WORK.

17. *Ice, Water, and Steam are different forms of the same kind of Matter.*—(*a*) Procure a lump of ice and notice that it is a solid or has a particular shape of its own, which as long as the day is sufficiently cold, remains fixed.

(*b*) With a sharp brad-awl or the point of a knife break it up into pieces, and put a convenient quantity of them into a beaker. Place the beaker in a warm room, or apply heat from a laboratory burner or spirit lamp. The ice disappears, and its place is taken by what we call water. Notice the characters of the water are those of a liquid. It has no definite shape, for by tilting the beaker the water can be made to flow about.

(*c*) Replace the beaker over the burner and go on warming it. Soon the water boils, and is converted into vapour, which spreads itself throughout the air in the room, and seems to disappear. The vapour can be made visible by blowing cold air at it, when it becomes white and visible, but is really no longer vapour, but has condensed into small drops of water.

18. *Solid Lead assumes the Liquid Condition when Heated.*—Heat a piece of lead or zinc in an iron spoon. Observe it eventually changes into a liquid, and that more heating is required to effect the change than in the case of ice.

The same kind of Matter can exist in all three Forms.—To the fact which has now been learnt that there are three kinds of material things, we must add another idea; viz., that the *same matter can exist in all three forms.* The change in the state of matter, whether from the solid to the liquid condition, or from the liquid form to the gaseous state, is most easily brought about by heating the material thing under consideration. Reverse changes, viz., from gas to liquid, and from liquid to solid, can be effected by cooling.

As will be more fully seen in subsequent chapters, the degree of heating required to bring about the above changes varies very greatly with different substances. Iron must be heated very much more than ice before it can become a liquid. Alcohol, again, has to be cooled to a much greater extent than water before the liquid condition gives place to that of a solid.

When a substance has, as a result of heating, successively passed through the solid, liquid, and gaseous states, then if the conditions are reversed and the gas is continuously cooled, the liquid form is first reassumed, and subsequent cooling causes the liquid to change again into the original solid.

Sudden and Gradual Changes of State.

EXPERIMENTAL WORK.

19. Warm a dry flask by twirling it between the finger and thumb above the flame of a laboratory burner. When it is too warm to bear the finger upon the bottom, introduce a crystal of iodine, and notice it is at once converted into a beautiful violet vapour. Notice the formation of crystals on the inside of the flask as it cools.

20. Gently heat a few crystals of sal-ammoniac (ammonium chloride) in a dry test tube. Notice the rapid conversion of the solid into a vapour and its deposition on the cold upper part of the tube. This is called *Sublimation.*

21. Warm a lump of sealing-wax or bicycle cement in an iron spoon, and notice the gradual conversion into a liquid.

The Change from one State to another may be Sudden or Gradual.—The circumstances attending the change from the solid to the liquid, or from the liquid to the gaseous state, are not always the same as in the case of water. When solid iodine is heated, it appears to suddenly pass from the condition of a solid to that of gas. Camphor is another instance of this sudden transition from solid to vapour. When, on the other hand, sealing-wax is heated, it very gradually passes into the liquid condition, and may be obtained in a kind of transition stage—neither true solid nor true liquid.

There is no hard and fast line between the three conditions of matter. The reader will find as his knowledge extends that intermediate states are known between those conditions we have mentioned; but for the present it will be best to confine the attention to this simple division, reserving for future work a study of these gradations.

Indestructibility of Matter.

EXPERIMENTAL WORK.

The meaning attached by men of science to the expression *indestructibility of matter* will be clear after a few experiments have been performed.

22. *No Loss of Matter during Evaporation.*—Boil water gently in a retort fitted like that in Fig. 12. The steam passes through a tube surrounded by a wider tube in which cold water is kept flowing. Catch the condensed steam in a flask placed at the lower end of the inside tube. If none of the steam escapes, the water thus collected will be found to have the same mass as that boiled away.

23. *No Loss of Matter during Melting.*—Place a piece of ice in a flask suspended from one arm of a balance. Counterpoise the flask with the ice in it; then melt the ice by warming the flask, and show that the counterpoise is unaltered.

24. *No Loss of Matter accompanies Solution.*—Put some water in a flask and some salt in a piece of paper (Fig. 13). Counterpoise the flask of water and the paper of salt together and then dissolve the salt in the water. The total mass remains unaltered.

25. *No Loss of Matter accompanies Chemical Change.*—(*a*) Put a piece of phosphorus of about the size of half a pea at the bottom of a flask; insert a well-fitting cork, and weigh the whole. Remove the cork from the flask, set fire to the phosphorus by holding the flask near a flame, replace the cork rapidly, and again weigh the whole apparatus.

The mass will be practically the same in both cases, because nothing has been added or taken away from the total quantity of matter contained in the flask.

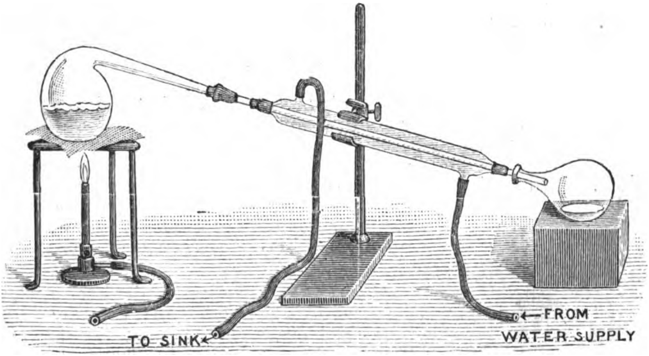


FIG. 12.—Condensation of Steam.

(*b*) Place a small piece of magnesium ribbon in a porcelain crucible, and determine, by weighing, the mass of the ribbon and crucible. Then ignite the magnesium, and when it has burned out again find its mass. The mass will be found greater than before.

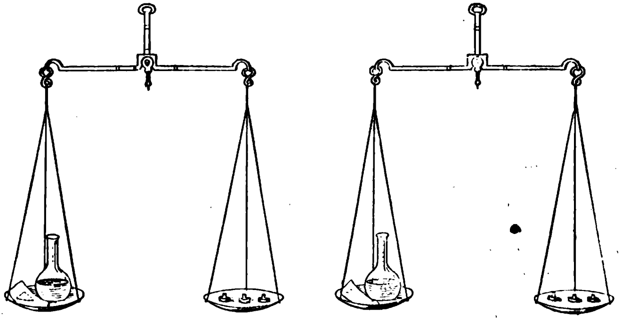


FIG. 13.—There is no change of mass when salt is dissolved in water.

(*c*) Connect two flasks containing a little hydrochloric acid and ammonia respectively, and fitted with india-rubber stoppers having a single hole, through which a piece of glass tubing passes (Fig. 14). Suspend the whole apparatus from a balance, and counterpoise it. Notice that a white cloud gradually forms owing to the combination of the two gases. But though these solid particles forming the cloud are produced, the counterpoise is not disturbed; therefore the mass has not changed.

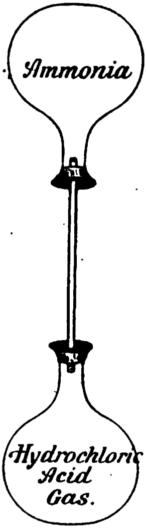


Fig. 14.—When ammonia gas unites with hydrochloric acid gas to form a solid (ammonium chloride) there is no change of mass.

Even in cases where the destruction of matter appears manifest it can be shown by suitable experiments that there has really been a formation of new kinds of matter, which under ordinary conditions are invisible. Thus, in the case of a burning candle, which is apparently destroyed as it burns, the following experiments show what really takes place.

26 (*a*). Over a burning candle hold a white glass bottle which has been carefully dried inside and out. Observe that the inside of the bottle becomes covered with mist, and after a short time drops of liquid are formed which run down the sides of the bottle. *The burning of the candle has resulted in the formation of a new form of matter, viz., water.*

(*b*) Allow the candle to burn in a similar bottle placed on the table. After a time the candle ceases to burn, and when this has happened take the candle out and cover the bottle over with a glass plate. Notice that no change seems to have taken place in the gas which filled the bottle. Now pour some clear lime-water into another clean bottle and shake it up; the lime-water remains clear. (There may be a slight milkiness owing to the presence in the air of the gas which is formed. If so, the experiment must be made comparative.) Lift off the glass plate and do the same with the bottle in which the candle has been burnt; the lime-water turns milky. *The burning of the candle has also resulted in the formation of a new kind of matter, viz., a gas which turns clear lime-water cloudy.*

No kind of Matter can be Destroyed.—There is a certain fixed amount of matter in the universe which never gets any less and never any greater. If we confine our attention to the earth, we cannot say that it never receives an addition to the matter of which it is built, for every year it is receiving numbers of small solid bodies which are continually falling upon its surface from outside space. But the statement means that in those cases in which it is popularly supposed there is a loss of matter, for instance when a fire burns out, no such destruction has taken place, but only a change in the form assumed by the matter. This will be made quite clear if you follow out what really takes place when a candle burns and, as it would seem, gradually disappears.

The Burning of a Candle.—The candle ceases to exist as tallow or wax, or whatever it is made of, and assumes new forms, still material, one liquid, the other a gas which turns lime-water milky. When all the liquid formed and all the gas which turns lime-water milky are weighed, it is found that these two things together actually have a greater mass than the part of the candle which has disappeared had. The reason why there is an *increase* of mass will be explained later. The arrangement for performing this experiment is shown in Fig. 15. The candle is burned in a wide tube, fitted with a cork at the bottom with holes in it to allow the air, which is necessary to help the candle to burn, to pass in. The tube is filled with a substance which has the power of arresting the products of the burning. Such a substance is caustic soda, which is used in the form of lumps. Air is drawn through the apparatus as shown by the arrows.

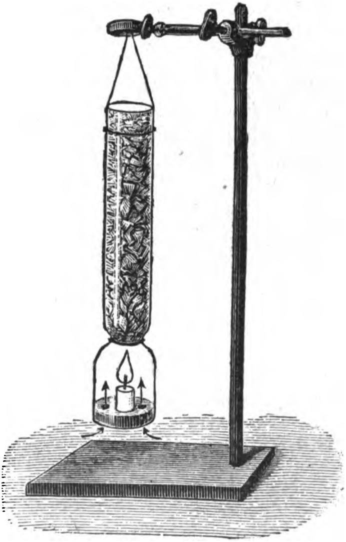


Fig. 15.—Apparatus to show that no matter is destroyed when a candle burns.

Before the experiment is started, the candle is weighed with the tube containing the lumps of caustic soda. After the experiment the same things are weighed over again. It will be found that the tube has increased in mass to a greater extent than that of the candle has been diminished. We may be quite sure, therefore, that there has been no loss of matter. The gain is due to a gas taken from the air by the candle when burning. You will understand this better after you have studied the lessons on chemistry.

The Burning of Phosphorus.—When phosphorus is allowed to burn in a closed flask as in the experiment described on p. 14, there is no alteration in the quantity of matter before and after the burning, as can be shown by weighing. What happens in the flask is very simple, though probably it will not be fully understood until the Chemistry Section has been studied. In the first place there was phosphorus and air (the latter containing oxygen and nitrogen) in the flask. When the phosphorus takes fire it unites with the oxygen to form an oxide of phosphorus (phosphorus pentoxide). After a short time the phosphorus ceases to burn because either it has all been burnt or has used up all the oxygen, in which latter case there is nothing left to support combustion. Upon opening the flask there will be found in it a gas, nitrogen, in which a candle or a taper or anything requiring oxygen will not burn. The fumes of phosphorus pentoxide formed by the combustion of the phosphorus will be found as a white substance deposited upon the inside of the flask. And if too large a quantity of phosphorus was used, some of it will be found uncombined at the bottom of the flask.

CHIEF POINTS OF CHAPTER I.

By **matter** is meant *all things in or out of our world which we can become aware of by the help of our senses.*

Different kinds of Matter.—(1) *Solids.* (2) *Liquids.* (3) *Gases.*

Liquids and gases are sometimes classed together as *fluids.*

A **solid** does not readily alter its size or shape. It will keep its own volume and the same form unless subjected to a considerable force.

A **liquid** adapts itself to the shape of the lowest part of the vessel containing it; but the conditions remaining the same, it keeps its own size or volume, however much its shape may vary.

Gases are easily compressible and expand indefinitely.

Distinctive Characters of Solids.—(1.) Elasticity of elongation, flexure, and torsion; (2) Tenacity; (3) Ductility; (4) Hardness.

Distinctive Characters of Liquids.—(1) When not held by the sides of a vessel they *flow*. (2) When at rest they have a horizontal surface. (3) They communicate pressure equally in all directions. (4) They can be separated into drops which will run together again.

The same kind of Matter can exist in all three Forms.—(1) Ice, water, and steam are different forms of the same kind of matter. (2) Solid lead assumes the liquid condition when heated. The change from one state to another may be sudden or gradual.

Indestructibility of Matter.—There is no loss of matter during (1) evaporation, (2) melting, (3) solution, (4) chemical change.

QUESTIONS ON CHAPTER I.

1. Give some of the properties which are possessed by all kinds of matter and explain in your own words what is meant by a property.

2. What experiment could you perform to show that a solid, say a billiard ball, is elastic? Explain as well as you can what you mean by elasticity.

3. The same portion of matter can, under suitable conditions, assume different states. Describe fully some experiment which illustrates this statement.

4. What evidence can you give that the different states of matter gradually shade into one another?

5. What properties are generally associated with matter in the solid form? Give a definition of a solid which includes the chief of these.

6. In what respects are liquids different from solids?

7. How do gases and liquids differ?

8. What property in particular is possessed by liquids and not by solids? And what character has a gas which neither liquids nor solids possess?

9. What property is it which liquids possess which enables them to form drops? Describe another experiment which also shows the possession of this property by liquids.

10. Give in the form of a definition the distinctive properties of a liquid. What name do we give to the property which prevents liquids from being perfectly fluid, and what do you know about it?

11. Describe experiments in support of the assertion that liquids communicate pressure equally in all directions.

12. How would you show by experiment that the mass of the same portion of matter in different states is constant?

13. On what grounds is the assertion that "Matter is indestructible" based?

14. Describe fully an experiment with which you may be familiar to prove that matter is indestructible.

15. What are the three forms of matter, and what are their distinctive features? Give two examples of kinds of matter of which all the three forms are known to you, and state the conditions under which they exhibit the different forms.

CHAPTER II

MEASUREMENT OF SPACE

Measurement of Length.

EXPERIMENTAL WORK.

27. *Inches and Centimetres.*—(*a*) Procure a rule divided into inches and parts of an inch on one edge, and centimetres and parts of a centimetre on the other. Examine the divisions. Measure the length of this page both in inches and centimetres; also determine other lengths in the two systems of measurement.

Put down the results in parallel columns, as shown below, and from them calculate the number of centimetres in an inch.

Length in centimetres.	Length in inches.	$\frac{\text{No. of centimetres.}}{\text{No. of inches.}}$

(*b*) Draw a line a metre long and one a yard long close to it. Measure the length of the metre line in inches and fractions of an inch, and the length of the yard line in centimetres. In this way find

Number of inches in one metre = 39·3.
Number of centimetres in one yard = 91·4.

(*c*) Draw a line one foot long and find its length in centimetres; draw another a decimetre long and find its length in inches. In this way determine

Number of centimetres in one foot = 30·5.
Number of inches in one decimetre = 3·9.

(*d*) Measure the length of your desk, or of a table, or other convenient object, in inches and decimals (tenths) of an inch. Determine the same length in metres and decimals of a metre. Use the results to determine the number of inches in a metre, thus :—

Length in inches.	Length in metres.	$\frac{\text{No. of inches.}}{\text{No. of metres}}$

28. *Simple application of Measurements of Length.*—Measure the circumference of a wooden cylinder by winding a strip of paper around the curved surface and pricking a hole through the strip where it overlaps (Fig. 16). Determine the length of the paper between the two pin-pricks by taking off the paper and measuring it with a centimetre scale. Next measure carefully the diameter of the cylinder. Repeat the experiment with other objects, such as a cylindrical canister or glass bottle or disc. Set down the results in parallel columns and use them to find the ratio of the circumference of a circle to the diameter.

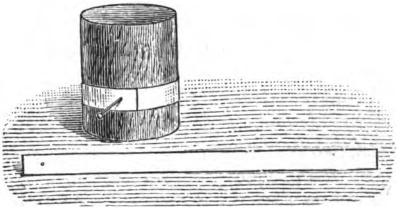


FIG 16.—How to measure the circumference of a cylinder.

Diameter.	Circumference.	$\frac{\text{Circumference.}}{\text{Diameter.}}$

Measurement of Length.—Whenever we measure a length, what we do is to compare it with another length which is called the standard or unit. A standard of length is necessary to avoid confusion, for if no standard existed some people might use one length when measuring, and other people might use an entirely different length under the same name. Every one knows that British people, when they speak of a length, express it as yards, feet, inches, or one of the other measures which have been learnt in Long Measure or Measures of Length.

Most thoughtful persons have said to themselves at one time or another—What are these yards, feet, and so on? How does the maker of a rule know how long a yard has to be? And how is it that if you buy a yard measure in London, Manchester, or any other town, it is always the same length? These are all very important questions, and we must try to answer them.

What a Yard is.—In a strong room of the Board of Trade in London there is a fire-proof iron chest which contains a bar of bronze. Into this bar, near each end, are sunk two golden studs, and across each stud fine lines are drawn. The distance between these marks (when the bar is at a certain temperature, called sixty-two degrees Fahrenheit, which you will understand before you get to the end of this book) is what is called the **Imperial Standard Yard.** This is the British Standard of length. Several exact copies of this bar have been made and are securely kept in different places. There is consequently very little danger of all the bars being burnt or lost at the same time. All yard measures should be the same length as the distance between these marks. The yard is divided into three equal parts, and each of these is called a **foot.** A foot is divided into twelve equal parts, and each part is called an **inch.**

The Metre.—Lengths are not measured in yards, feet, and inches in all countries. In France, and most other countries, the standard length is what is called a **metre.** In Sèvres, a bar of a similar kind to that kept by our Board of Trade is carefully preserved. The distance between the two marks in the golden studs is the standard known as the metre. The metre is longer than the yard. You know there are thirty-six inches in the yard, but the metre measures about thirty-nine and one-third inches, or three feet, three and one-third inches (3 feet 3⅓ inches). This number is easily remembered because it only contains the figure 3.

Divisions of the Metre.—The metre is not divided in the same way as the yard. A much better plan is adopted. First the metre is divided into ten equal parts, each of which is called a **decimetre**, so that you may write:

10 decimetres make one metre.

The distance from one end to the other of Fig. 17 is a decimetre.

Next, each of these decimetres is divided into ten equal parts, each of which is a **centimetre**, and it takes one hundred of them to make a metre, consequently you may say:

10 centimetres make 1 decimetre.
100 centimetres „ 1 metre.

The distance from one number to the next in Fig. 17 is a centimetre.

Then, each centimetre is divided into ten equal parts, and each of these is called a **millimetre**, and it takes one thousand of them to make a metre. The smallest divisions in Fig. 17 are millimetres.

Thus, you see that you may write a table for the sub-divisions of the metre which you will have no trouble in remembering:

10 millimetres make 1 centimetre.
10 centimetres „ 1 decimetre.
10 decimetres „ 1 metre.

For lengths greater than a metre the same simple plan is used. A length which contains exactly ten metres is called a **dekametre**; one which just contains a hundred metres is called a **hektometre**; and one which is exactly a thousand times as long as a metre is called a **kilometre**. These can be put together in another little table:

10 metres make 1 dekametre.
10 dekametres „ 1 hektometre.
10 hektometres „ 1 kilometre.

Comparison of British and Metric Measures.—On the Continent the metric system of measurement is used almost entirely. The sign posts on the roads do not show how many miles it is to the next village or town, but the number of kilometres. Linen and silks and such materials are not sold by the yard, but by the metre, and shorter lengths are measured in centimetres. You will find it useful to remember that about 2½ or 2·5 centimetres are equal to 1 inch, 30·5 centimetres are equal to 1 foot, and eight kilometres are about five miles.

The metric system of measurement is thus much simpler than the British, for all the divisions and multiples of the standard go in tens. In our system, compound reduction, such as reducing miles to inches, involves a long sum, but in the metric system, kilometres can be transformed into millimetres by merely moving the decimal point. A measure in any denomination in the metric system can in fact be converted into units of the next smaller kind by moving the decimal point one place to the right, and into units of the next larger kind by moving the decimal point one place to the left.

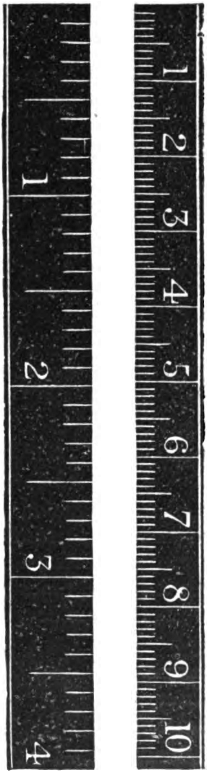


FIG. 17.—British and metric measures compared.

Relation between British and Metric Units of Length.—The exact relations between linear measures in the British and Metric systems of units are shown in the following tables, and also in Fig. 17.

Metric to British.

1 millimetre = 0·039 inch.
1 centimetre = 0·394 inch.
1 decimetre = 3·937 inches.
1 metre = 39·371 inches.
1 metre = 3·281 feet.
1 metre = 1·094 yards.
1 kilometre = 0·621 mile.

British to Metric.

1 inch = 25·399 millimetres.
1 foot = 0·305 metre.
1 yard = 0·914 metre.
1 mile = 1609·000 metres.
= 1·609 kilometres.

The Conversion of Units.—It is often necessary to convert British into Metric measures and *vice versa.* This is merely a matter of simple multiplication. Thus:

Convert 12·7 inches into centimetres.

1 inch = 2·54 cms.

Therefore 12·7 inches = 2·54 × 12·7 cms.
= 32·258 cms.

The following examples will serve to make the student familiar with the use of conversion factors :

(i) If a man walk 12 miles in 3 hours, how many kilometres would he walk in the same time ?

(ii) If the length of a certain hill is 1963 metres, what is the length in feet ?

(iii) A merchant wishes to order 220 feet length of a certain material from a continental firm which sells the material in metres. How many metres should he order ?

(iv) Convert (*a*) 17·6 inches into centimetres.
(*b*) 2 ft. 3 in. into decimetres.
(*c*) 22 yds. 7 ft. 5 in. into metres.

(v.) Convert (*a*) 30 cms. into inches.
(*b*) 5·7 dms. into feet.
(*c*) 113·54 metres into yards.

Measurement of Area.

EXPERIMENTAL WORK.

29. *Units of Area.*—Draw a square inch and a square centimetre, side by side, as shown in Fig. 18.

30. *Measurement of Area.*—(*a*) Draw a square decimetre and divide it into square centimetres, as shown on a reduced scale in Fig. 19. The area of the square is thus shown graphically to be equal to the length multiplied by the height. Now draw two or three oblongs and determine their areas by means of this rule. Determine the areas of the square and oblongs both in square inches and square centimetres, and use your results to find the number of square centimetres in one square inch, thus :

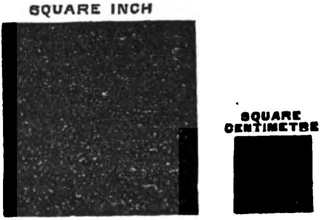


FIG. 18—Square inch and square centimetre.

Area of a given rectangle in square inches.	Area of same rectangle in square centimetres.	$\dfrac{\text{Square centimetres.}}{\text{Square inches.}}$

(*b*) Draw a square foot and a square decimetre and find the number of square decimetres in the square foot, and the fraction which one square decimetre is of one square foot.

(*c*) If convenient, draw a square yard and a square metre upon a black-board or a large sheet of paper. Determine the area of the square yard in decimals of a square metre, and the area of the square metre in square yards. To obtain the latter result, the number of square inches in one square metre is determined, and the result divided by the number of square inches in a square yard.

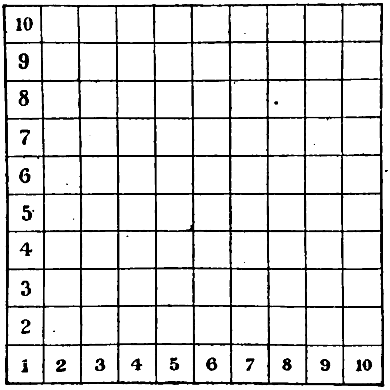


FIG. 19.—Square divided into units of area.

31. *Determinations of Areas.*—(*a*) It has already been explained that the area of a square or an oblong can be determined by dividing the figure into units of area and counting the number of units. Paper can be procured divided into squares of a definite size, similar to those represented in Fig. 20. By means of "squared" paper of this kind, the area of any figure can be found by drawing the figure upon the paper and counting the number of squares embraced by the boundary lines. If "squared" paper

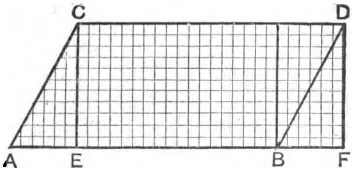


FIG. 20.—The Area of the parallelogram CABD is the same as that of the oblong CEFD.

is not available, the area is still easily found by dividing it up into square centimetres with a **T**-square and set squares.

(*b*) Draw an oblong, such as CEFD (Fig. 20), upon squared paper, and find the number of squares it contains. Draw a parallelogram CABD with a base equal to the base of the oblong, and a height equal to that of the oblong. Count the number of squares in the parallelogram (counting the portions of squares as quarters, halves, and three-quarters). The number will be the same as that found for the oblong. No matter what parallelogram is drawn, the area will be found to be the same as that of an oblong on the same base and having the same height.

(*c*) Draw a parallelogram on paper or thin card and then cut it in two from corner to corner. You have now two triangles, and by laying one on the other you will find that they fit and are equal.

(*d*) Draw an irregular figure upon squared paper and count the number of squares embraced by it (Fig. 21). If the size of the squares is known, the area of the figure can be determined in this way. The area of any irregular figure can evidently be determined by tracing the figure upon squared paper and counting the number of squares included by the outline, or by actually dividing it into square centimetres.

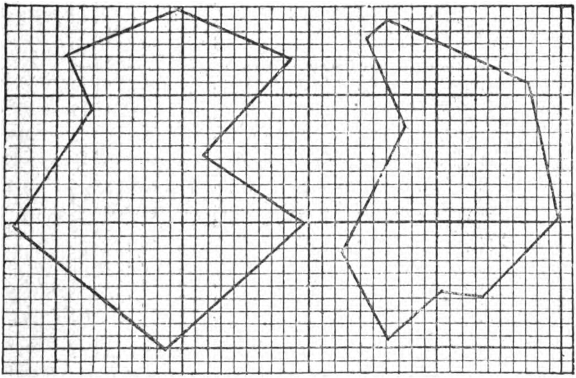


FIG. 21.—Method of determining area of irregular figures.

Measurement of Area.—Most readers of this book will probably already know the difference between lengths and areas. But to make quite certain we will take a few simple examples.

Provided with a rule, it would be easy to measure the length of the room and its breadth or width. If we had a ladder we could, in the same way, measure its height. Now, if we were going to have a carpet put down, we should give the upholsterer the order, and he would pay us a visit to measure the floor. You know very well it would not be enough for him to measure the length of the room only, or its width only, because both of these are measures of length. To know how much carpet he wants the workman must find out the amount of surface the floor has, or what is called its **area**. To do this he measures both the length and width of the floor, and when he multiplies them together he gets the area, if the room is a square or oblong one. If he measures the length and width in feet, then by multiplying them together he gets the area of the floor in square feet; if the measurement of the length and width were taken in inches, the area in square inches would be obtained by multiplying them together.

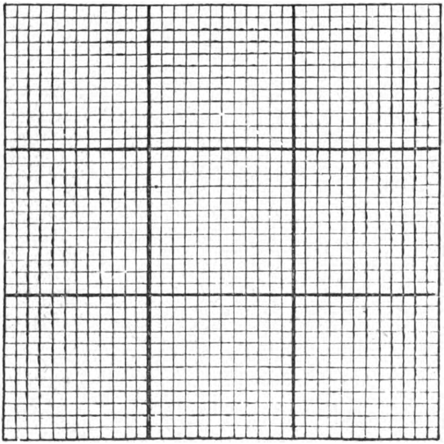


FIG. 22.—This represents a square yard reduced so as to fit this book. Each small square represents a square inch, and the large squares bounded by thick lines represent square feet.

Whenever areas are measured in this country, square inches, square feet, square miles, or some other unit from square measure is employed. 'Square measure' is obtained from 'long measure' by multiplying. Thus, as there are 12 inches in a foot, there are 12 × 12 square inches in a square foot. You will understand this by examining Fig. 22. Each of the large squares bounded by thick lines represents a square foot, but it is of course smaller than a real square foot.

Square Measure.—By referring to Fig. 22, which illustrates how a square yard may be divided into square feet, and square inches, and examining your squares of cardboard divided into square inches or square centimetres, it is easy to see how square measure is obtained from long measure. This may be put in the form of a table thus:

144 (= 12 × 12) square inches make 1 square foot.
9 (= 3 × 3) „ feet „ 1 „ yard.
30¼ (= 5½ × 5½) „ yards „ 1 „ pole.

How many square inches are there in a square yard? You can find out by counting the squares in Fig. 22, or by counting the squares in one of the areas representing a foot and multiplying the number by nine.

Square Metric Measures.—If instead of measuring the length and breadth of the floor in feet the workman had measured them in metres or decimetres, what would the area obtained by multiplying be measured in? Not in square feet, but in what is called square metres, square decimetres, etc. Square measure in the metric system is obtained from long measure in just the same way as we used in the case of inches. All we mean by the metric system is the plan of using metres, etc., instead of yards, etc., in measurements of all kinds. We can now write down the measures of area or surface in the metric system:

100 (= 10 × 10) square millimetres make 1 square centimetre.
100 (= 10 × 10) „ centimetres „ 1 „ decimetre.
100 (= 10 × 10) „ decimetres „ 1 „ metre.

A square decimetre is too large to be shown on this page. Fig. 23 shows two complete rows of square centimetres, but there are ten rows of this kind in a square decimetre. The centimetre *AGFE* in the top left-hand corner is divided into square millimetres. As 1 square centimetre contains 100 square millimetres, 1 square decimetre or 100 square centimetres contains 100 × 100 square millimetres, that is 10,000 square millimetres.

The size of a square centimetre is compared with the size of a square inch in Fig. 18. You will see that a square inch is much larger than a square centimetre. Each side of the square inch is 2·54 centimetres in length, so the number of square centimetres in a square inch is 2·54 × 2·54 = 6·45, or nearly 6½ square centimetres.

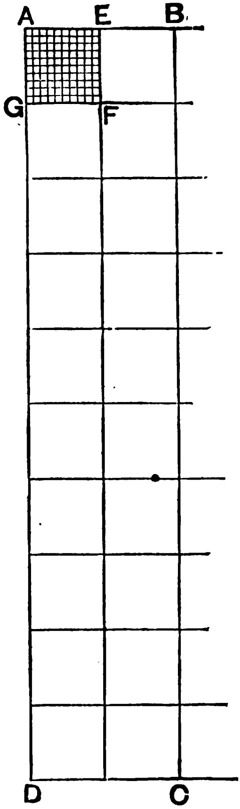


FIG. 23.—Square centimetres and square millimetres. Ten rows of ten square centimetres make one square decimetre.

Relation between British and Metric Units of Area.—These exercises have shown roughly the relation between the measurements of areas expressed in the metric and British systems of units. The exact proportions which the units of area in the two systems bear to one another are shown in the following table:—

Metric to British.

1 square centimetre = 0·155 square inch.

1 square decimetre = 15·500 square inches.

1 square metre = 10·764 square feet.

= 1·196 square yards.

1 are (100 square metres) = 119·603 square yards.

1 hectare (10,000 square metres) . . . . . = 2·471 acres.

British to Metric.

1 square inch = 6·451 square centimetres.

1 square foot = 9·289 square decimetres.

1 square yard = 0·836 square metres.

1 acre = 10·117 ares.

1 square mile = 258·989 hectares.

Measurement of Volume.

EXPERIMENTAL WORK.

32. *Units of Volume.*—(*a*) Procure a box or a block one cubic foot in size. The top, and, if possible, the other faces of the cube, should be divided into square inches.

Notice that the area of each face of the cubic foot is one square foot. Count the number of square inches marked on one face. Notice that 144 cubic inches could be cut out of a slab of the cube one inch thick. How many slabs having a thickness of one inch could be cut from one cubic foot, and how many cubic inches are there altogether in such a cube?

(*b*) Obtain a cubic centimetre of wood; a slab of wood 10 × 10 × 1 cm.; a rod of wood 1 × 1 × 10 cm.; and a cubic decimetre of wood.

How many cubic centimetres are there in the rod of wood? How many such rods would be required to make a slab of wood the same size as that supplied? How many cubic centimetres, therefore, does the slab contain? How many slabs would be required to make a cubic decimetre? How many cubic centimetres would be required to make such a cube? (*See* Fig. 24.)

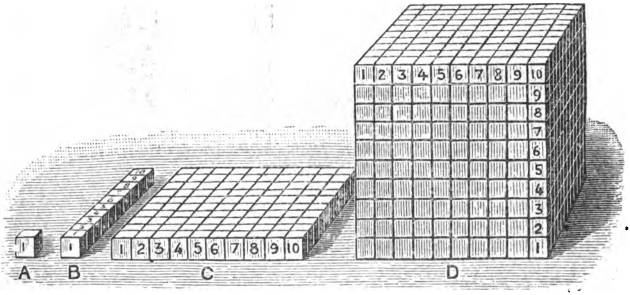


FIG. 24.—Ten cubes like *A* would make a rod like *B*. Ten rods like *B* would make a slab like *C*, and ten such slabs would make the cube.

(*c*) Compare the cubic centimetre of wood with a cubic inch of wood and the cubic decimetre with the cubic foot. Knowing that 2·54 cm. = 1 inch, calculate the number of cubic centimetres in one cubic inch.

33. *Capacity.*—(*a*) Cut out of cardboard a figure of the shape shown in Fig. 25 and of the size indicated by the numbers. Cut the cardboard half-way through at the dotted lines, and then bend it to form a cubical box which will hold 1 cubic decimetre, that is, *1 litre.* Bind the edges

together with glued tape, and varnish the box inside and out to make it watertight. Make a similar box having sides 1 inch in length, so that it will contain 1 cubic inch.

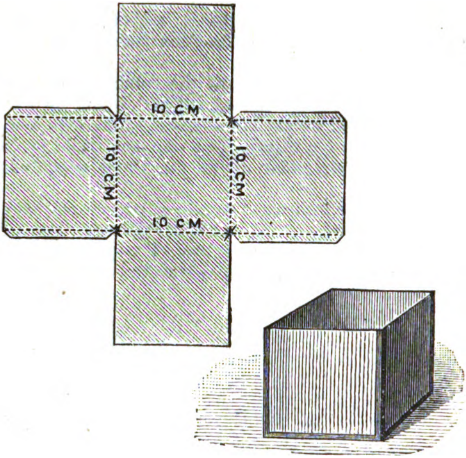


FIG. 25.—Sides of a cubic decimetre box.

(*b*) Fill the cubic inch box, from the last experiment, with water, and by pouring the water into a jar graduated into cubic centimetres, determine the number of c. cm. in a cubic inch.

34. *How to find the Volume of a Solid.*—(*a*) Fill the cubic inch box with water and pour the water into a narrow glass jar or bottle. Make a mark upon the bottle level with the top of the water. Repeat the operation until the vessel is full of water. A bottle graduated into cubic inches is thus obtained, and it can be used to determine roughly the volume of an irregular solid such as a piece of lead, a glass stopper, a few nails, or any solid heavier than water which will go into the bottle. Fill the bottle about three-quarters full of water; observe the level of the water, and then gently drop in the chosen object. From the rise of water-level which immediately takes place, the volume of the object can be estimated.

(*b*) Repeat the last experiment, substituting the jar graduated into c. cm. The volume of the solid used, in metric units, is shown by the rise of the water above its original level.

(*c*) If the object is lighter than the liquid employed, a sinker made of lead or iron should be employed. First place the sinker in water and notice the level; then take the sinker out of the water and tie it with thread to the light object, and place them both in the jar. The additional rise of level which takes place will give the volume of the object.

Measurement of Volume.—If we examine Fig. 26, which represents a cubic foot, and bear in mind what we have already learnt, we shall easily understand that each edge of the solid there represented is measured as a length. Each of its faces has an area, which can be obtained by multiplying together the lengths of two of the edges which meet at a corner. But the size of the solid, or the amount of room it takes up, or the space it occupies, is quite a different thing. This new measurement is what is called its **volume**.

The volume of a solid body is obtained by measuring in three directions. Just as to find the area of a surface we measure its length and breadth, so to measure the volume of a solid we must find in addition to measurements of length and breadth, another distance called the thickness. If we multiply length, breadth, and thickness together we obtain a volume or cubical content.

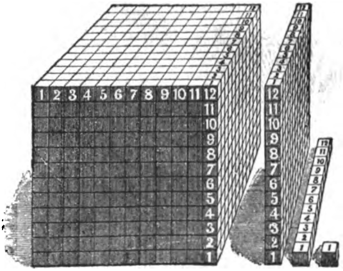


FIG. 26 —To explain why 1728 cubic inches make one cubic foot.

Returning to our cubic foot for a moment, let us find how many cubic inches it contains. We know already that any one of its faces covers 144 square inches of surface. In the cube we can think of a layer of 144 cubic inches, or little cubes each edge of which is an inch, and each face of which is a square inch. How many such layers are there in the whole cubic foot? Evidently there are twelve layers.

Consequently, in the whole cube we have 144 × 12 = 1728 little cubes the edges of which are one inch long and the faces of which are each one square inch. Or, one cubic foot contains 1728 cubic inches.

We could reason in the same way to find out how many cubic feet are required to build up a cubic yard. We may write down, therefore,

1728 (= 12 × 12 × 12) cubic inches make 1 cubic foot.
27 (= 3 × 3 × 3) „ feet „ 1 „ yard.

Metric Measures of Volume.—We proceed in a similar way when we wish to measure volumes by the metric system.

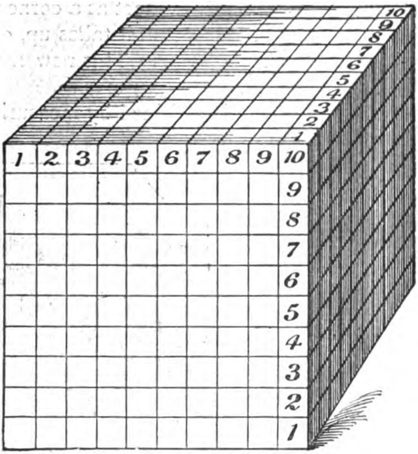


FIG. 27.—A cubic decimetre divided into cubic centimetres.

A block built up with cubes representing cubic centimetres is shown in Fig. 27.

The cube measures 10 centimetres each way, and its volume is therefore a cubic decimetre. You know there are 10 centimetres in a decimetre, so you may say the edge of the decimetre cube is 10 centimetres in length; the area of one of its faces is 10 × 10 = 100 square centimetres; and its volume is 10 × 10 × 10 = 100 × 10 = 1000 cubic centimetres.

The Litre.—If a hollow cube is made 1 decimetre long, 1 decimetre broad, and 1 decimetre deep, it will hold 1000 cubic centimetres of liquid. This capacity is called a **litre**. All liquids are measured in litres in countries where the metric system is adopted. Thus in France, wine, milk, and such liquids, are sold by litres instead of by pints. A litre is equal to about one and three-quarters English pints.

We may now write some of the measures of volume in the metric system:

10 centilitres make 1 decilitre.
10 decilitres „ 1 litre (1000 cubic centimetres).
10 litres „ 1 dekalitre.
10 dekalitres „ 1 hektolitre.
10 hektolitres „ 1 kilolitre or 1 cubic metre.

Cubic Centimetres and Cubic Inches.—It has already been found that one inch is 2·54 centimetres long. The area of one square inch, that is of a surface 1 inch long and 1 inch broad, is therefore 2·54 × 2·54 or 6·45 square centimetres. The volume of a cubic inch, if the measurements are made in centimetres, is 2·54 × 2·54 × 2·54 cubic centimetres, that is 16·38 cubic centimetres. It would thus take 16·38 cubic centimetres, or roughly 16⅓ cubic centimetres, to make one cubic inch. Sixty-one cubic inches are about equal to the volume of one decimetre.

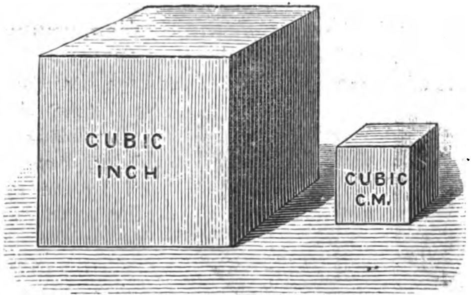


FIG. 28.—It would take 16⅓ cubic centimetres to make 1 cubic inch.

Relation between British and Metric Units of Volume.—Your measurements will show approximately the relations between the units of volume or capacity in the British and metric systems of measurement. The exact equivalents are as follows :—

Metric to British.

1 cubic centimetre = 0·061 cubic inch.
1 cubic decimetre = 61·027 cubic inches.
1 cubic metre = 35·316 cubic feet.
= 1·308 cubic yards.
1 litre = 1·761 pints.

British to Metric.

1 cubic inch = 16·386 cubic centimetres.
1 cubic foot = 0·028 cubic metre.
= 28·315 cubic decimetres.
1 cubic yard = 0·764 cubic metre.
1 pint = 0·568 litre.
1 quart = 1·136 litres.
1 gallon = 4·543 litres.

Simple Application of Volume Measurement.—The student cannot have failed to notice that the

volume of a cube = area of the base × height.

The volume of any rectangular block, or of a cylinder, can be calculated by the application of the same rule. This can be easily understood by referring to the accompanying diagrams (Fig. 29, A), which may be taken to represent solids divided into slabs one centimetre thick, while the lowest slab of each block illustrated is divided into small cubes representing cubic centimetres. The number of cubic centimetres in the bottom slab of each solid is evidently the same as the number of square centimetres in the base.

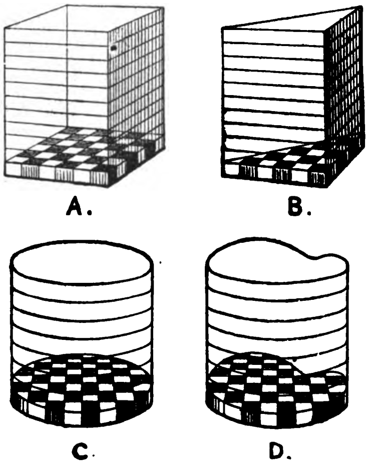


FIG. 29.—To illustrate how the volumes of bodies having the same sectional area all the way up are determined by multiplying the area of the base by the height.

Hence, if the base had an area of 30 square centimetres, a slab 1 centimetre high would contain 30 cubic centimetres. Two such slabs would therefore contain 60 cubic centimetres, three slabs 90 cubic centimetres, and so on for any number of slabs. The volume of any block having parallel ends, and the same width and breadth all the way up may evidently be reasoned out in the same manner, being equal to the area of the base multiplied by the vertical height.

CHIEF POINTS OF CHAPTER II.

Units of Length.

Metric	British
Metre (= 1$\frac{1}{11}$ yard)	Imperial yard
10 Decimetres 100 Centimetres 1000 Millimetres	3 feet 36 inches

Units of Area.

Metric	British
Square metre (= 1·2 sq. yards)	Square yard (= 0·836 sq. metre.)
100 sq. mm. = 1 sq. cm. 100 sq. cm. = 1 sq. dm. 100 sq. dm. = 1 sq. metre	144 sq. in. = 1 sq. ft. 9 sq. ft. = 1 sq. yd.

Units of Volume.

Metric	British
Litre (= 61·03 c. in.) 10 Decilitres 100 Centilitres 1000 Millilitres (c. c.)	Cubic yard (= 0·8 c. metre.) 1728 c. in. = 1 c. ft. 27 c. ft. = 1 c. yd.

NOTE.—1 litre = 1·76 pints; 1 pint = 0·57 litre.

QUESTIONS ON CHAPTER II.

1. Multiply 10·4 square centimetres by 15·5 decimetres, and state the result both in cubic centimetres and in litres.

If the volume in question were filled with water at 4° C., what would the weight of the water be?

2. What is the cubical content, in litres, of a box of which the inside dimensions are as follows:—length 25 centimetres, breadth 12 centimetres, and depth 8 centimetres? What is the weight in kilogrammes of the water it would hold?

3. One pint is equal to 34·7 cubic inches, and 1 inch is equal to 2·54 centimetres. How many pints are there in 1000 cubic centimetres?

What is the name given to a volume of 1000 cubic centimetres?

4. How would you determine the volume of a pebble in cubic centimetres?

5. What is the necessity for units of length, area, and volume? What is the unit of length in common use in this country, and how may it be defined?

6. What is the unit of length in the metric system? What relation was it originally meant to bear to the earth's circumference? How would you define the metric unit of length in common use?

7. What advantages do you associate with the use of the metric system?

8. Give the multiples and sub-multiples of the unit of length in the British system. How are they related to one another?

9. What names are given to the multiples and sub-multiples of the metre? Compare the metre and the yard in terms of one another.

10. Compare and contrast the British and metric systems of area and volume.

11. Explain how the metric units of volume and length are related. Is there any such simple relation in the case of British units?

12. What is meant by a unit of length, and why is it necessary to have such a unit?

Give particulars of the units of length in use in this country and on the Continent, and give your opinion as to whether one of the units you give is more convenient than the others, and if so, why?

CHAPTER III.

MASS AND WEIGHT.

Mass and its Measurement.

EXPERIMENTAL WORK.

35. *Meaning of Mass and Weight.*—(*a*) Take two pieces of iron or brass, called in ordinary language, "pound" and "half-pound" weights; or a "pound" and a "two-pound" will do. Lift the two pieces of metal. One feels heavier than the other, that is, the masses are different.

(*b*) Place a certain amount of lead in one pan of a balance, and counterpoise it with cotton-wool in the other pan. The masses are equal but the volumes are different (Fig. 30).

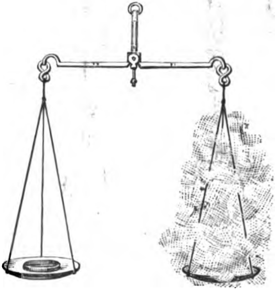


FIG. 30.—1 lb. of lead has the same mass as 1 lb. of cotton wool.

(*c*) Drop one of the pieces of metal; it falls to the ground on account of the earth's pull upon it. If the attractive force were doubled when you held the piece of metal, what difference would you feel? If the attraction suddenly ceased, what would happen when you released your hold of the piece of metal?

(*d*) Wind a piece of iron wire a yard long round a smooth walking-stick or a round ruler, and so make a coil. Hang one end of the coil on a support, and to the other attach the iron pound. Observe that the spring is made longer by the downward pull of the iron (Fig. 31).

(*e*) Examine the parts of a spring balance (Fig. 32). Attach one ounce to the balance and show that the marker is pulled down to the division 1. The pull of the spring upwards and of the ounce downwards are equal.

(*f*) If possible, using a delicate spring balance, such as is used for weighing letters, show that the downward pull of a mass of iron can be increased by holding a strong magnet under it.

36. *Measurement of Mass.*—(*a*) Examine examples of British masses, *e.g.* an ounce, a pound, a half-hundredweight. Also examine a box of metric masses, generally spoken of as a box of "weights."

(*b*) Compare a pound with a kilogram. Hang the 100 gram mass from a spring balance, and notice that the downward pull or its weight is equal to the weight of 3½ ounces. What, then is the British equivalent of the weight of a kilogram? It is evidently equal to the weight of 3½ ounces × 10 = weight of 35 ounces = weight of 2⅕ lbs. (roughly).

What Mass is.—Before we attempt to learn how mass is measured we must know what is meant by this word. When we say that the mass of one piece of metal is twice as great as the other, we mean that one of them contains twice as much iron, brass, or other material as the other. And always when we speak of the **mass** of a body we mean the **amount of stuff or matter**, of whatever kind, it contains. Though the masses of two lumps of material may be equal, as can be shown by making one balance the other in a pair of scales, their volumes may be very unequal. This is very well seen by comparing equal masses of lead and cotton wool.

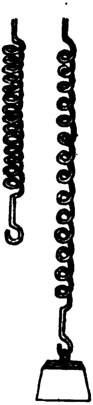


FIG. 31.—Principle of the spring balance.

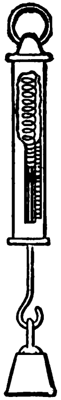


FIG 32.—A spring balance.

The mass of a thing is not the same as its weight, though one is often confused with the other. Keeping in mind what is meant by mass, we can, by doing one or two experiments, find out exactly what should be meant when the word weight is used.

Mass is not Weight.—If the mass of a pound is dropped from the hand it falls to the ground. If the same mass is hung upon the end of a coil of iron wire, the coil is made longer by the downward pull of the mass fixed to its end. The amount by which a steel spring is lengthened, as the result of such downward pull of masses attached to its end, is used to measure their **weights** in the instrument called a **spring balance**. If we use a very delicate balance of this kind, like those used in weighing letters, we can make the **weight** of a small piece of iron hung on to the balance appear greater by holding a strong magnet beneath it. But, though the weight may appear greater, the mass or quantity of matter is, of course, the same whether the magnet is under the iron or not.

If you have understood these experiments you will have no trouble in seeing clearly what exactly is meant by the weight of a body. Unsupported things fall to the ground; a fact which can also be expressed by saying that they are attracted to the earth. Now, even when they are supported, like the objects on the table, the earth attracts them just as much, only the table prevents them from falling, as they would do if there were no table there. **The force with which a body is attracted by the earth is its weight.** But it must be remember that this force is just the same whether things actually fall to the ground or not. You become aware of the weight of a heavy thing when you hold it on the outstretched hand. You feel that it is only by using your strength, or as it is sometimes said, by exerting force, that you prevent it from falling. This force which you exert is equal to the weight of the heavy object. If you have understood this, and it is necessary that you should, you will never confuse mass and weight, for while **mass is the amount of stuff in a body, its weight is the force with which the thing tries to get to the earth.**

The Pull of the Earth.—Gravitation.—Experiments and observations made by Newton led him to the conclusion that it was the rule of nature for every material body to attract every other similar body, and that this force of attraction is pro-

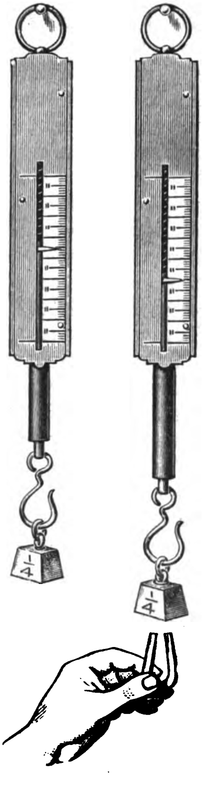


FIG. 33.—The iron weight may be made to appear heavier by a magnet, but the mass does not change.

portional to the masses of the bodies; a large mass exerts a greater force of attraction than a small mass. But the farther these bodies are apart the less will be the attraction between them, though it is not less in the proportion of this distance, but in that of the square of the distance. This diminution of a force according to the inverse proportion of the square of the distance applies to so many cases that it ought to be clearly understood before going further. To give an example: two bodies of equal mass are one foot away from one another and attract each other with a certain force, call it a unit force. One body is now moved until its distance is two feet away from the second body; what will be the force of attraction between them? The square of 2 is 2 × 2 = 4 and the inverse of 4 is ¼, therefore the force of attraction is one quarter of the unit force. In the same way, if the bodies were three feet apart, the force of attraction would be ⅑ of the unit force. Putting Newton's law together it stands thus: **Every body in nature attracts every other body with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between the bodies; and the direction of the force is in the line joining the centres of the bodies.**

Returning to the case of the falling body, think of a cricket ball on the top of a house. The earth attracts the ball, and, by Newton's law, the ball attracts the earth. The ball, if free to move, falls to the earth; to be correct, however, we must think of the ball and the earth moving to meet one another along the line joining their centres. But the ball moves as much farther than the earth as the earth's mass is greater than the ball's; and for practical purposes this is the same as saying that only the ball moves, and that the earth remains still. Were our methods of measurement sufficiently refined we should, of course, be able to measure the small amount of the earth's movement.

This force of attraction between all material bodies is called the force of gravity, but we must point out that this is only a name. Calling this force "gravity," and the rule according to which it acts the "law of gravity," does not teach us anything about the nature of the force itself. There is, however, no doubt about the reality of the attraction which bodies exert upon one another. So long ago as 1798 Cavendish measured the force of attraction between two lead balls, and his experiments have been repeated by a number of other investigators.

The Weight of a given Mass may vary from place to place.—Bearing the definition of weight in mind, it will be clear from Newton's law of gravitation that since a mass is farther away from the earth (which acts exactly as if its whole mass were collected at its centre) when it is up in a balloon than when at the sea-level, the weight of this mass ought to be more at the sea-level, for it is there nearer the centre than when up in a balloon. This is found to be the case, but to actually demonstrate the difference in weight we must measure the weight by a spring balance as in Experiment 35 (*e*).

Similarly, because the earth is not a perfect sphere, but is flattened at the poles, points at the surface of the earth in the region of the tropics are at a greater distance from the centre than points in the neighbourhood of the poles. Consequently, the weight of a mass situated on the earth in the tropics should be less than the weight it would have if it were moved into the polar regions. This has been found to be the case.

The rotation of the earth is another disturbing influence. While places on the equator are carried round with a velocity of over a thousand miles an hour, those near the poles have but a very small velocity of rotation, while the pole itself is at rest. It is clear that if we consider a mass at the equator its tendency is to obey the first law of motion (p. 96), and to fly off at a tangent, and part of the force of gravitation is expended in preventing this flight—the remainder of the force of gravity is operative as the weight of the mass under consideration. At the pole there is no tendency to move off tangentially, and the whole of the force of gravitation is felt as the weight of the body. For this reason alone the mass would weigh less at the equator. At places intermediate between the poles and the equator the diminution in the weight of the body, or the diminution in the acceleration due to gravity, is less ; it diminishes as the nearness to the pole is increased.

Measurement of Mass.—Just as in measuring lengths we found it was necessary to have a standard with which to compare, so in measuring mass we must also have a standard or unit. Then we can say how many times the mass of a given body is greater or smaller than our unit. In this country the standard of mass is the amount of matter in a lump of platinum which is kept with the standard yard at the Standards Office. This lump of platinum is called the **imperial standard pound avoirdupois** (Fig. 34). The divisions, etc., of the imperial pound you have already learnt in your arithmetic lessons, under the name of "avoirdupois weight."

A mass of 1 lb. avoirdupois is kept at a weights and measures office in every city, so as to test the lb. "weights" used by tradesmen, and see whether they really have the mass of 1 lb. or are too light.

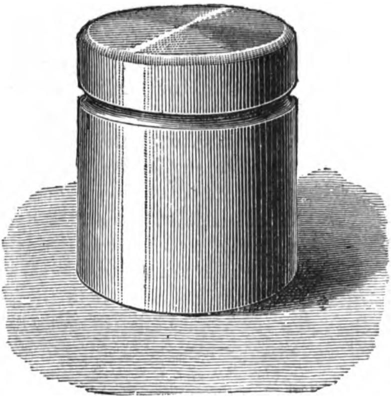


FIG. 34.—Exact size and shape of the British standard pound, made of platinum. From Aldous's *Course of Physics*. (Macmillan.)

AVOIRDUPOIS WEIGHT.[1]

16 drams	make	1 ounce.
16 ounces	"	1 pound.
28 pounds	"	1 quarter.
4 quarters	"	1 hundredweight.
20 hundredweights	"	1 ton.

---

[1] Remember this is a wrong use of the word. What ought it to be?

The Kilogram and Gram.—The standard of mass which is adopted in France, and in other countries where they use the metric system, is called the **kilogram.** The kilogram is the amount of matter in a lump of platinum which is kept in safety at Paris. It is bigger than the British pound; indeed it is equal to about two and one-fifth of these pounds. It is very interesting to know how the mass of a kilogram was obtained. It was agreed to give the name **gram** to the mass of water which a little vessel holding one cubic centimetre would contain.[1] The lump of platinum was made equal to the mass of one thousand cubic centimetres of water; it would therefore have the same mass as one thousand cubic centimetres of water, or, as you know this amount is called, a litre of water. The names used for the divisions, etc., of the gram are obtained in the same way as in the case of the metre, thus;

METRIC MEASUREMENT OF MASSES.

10 milligrams = 1 centigram.
10 centigrams = 1 decigram.
10 decigrams = 1 gram.
10 grams = 1 dekagram.
10 dekagrams = 1 hektogram
10 hektograms = 1 kilogram.

Relation between British and Metric Units of Mass:—

Metric to British.

1 decigram = 1·5432 grains.
1 gram = 15·4323 grains.
1 dekagram = 0·3215 oz. Av.
1 hektogram = 3·2574 oz. Av.
1 kilogram = 2·2046 lbs. Av.

British to Metric.

1 grain = 0·648 decigram.
1 oz. Tr. = 3·1103 dekagrams.
1 oz. Av. = 2·835 dekagrams.
1 lb. Av. = 0·4563 kilogram.

[1] The temperature being 4° C. But it is unnecessary at this stage to consider why the temperature must be mentioned.

How to remember Metric Measures.—As we have now described the metric measures of length, volume, and mass, this is the place to explain how they can all be easily remembered.

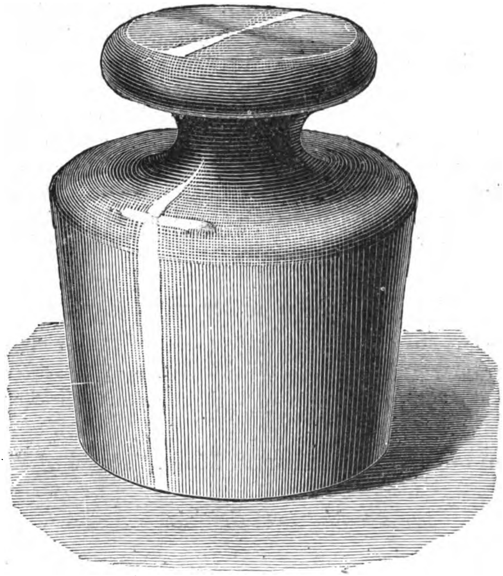


FIG. 35.—Exact size and shape of the metric standard of mass—the kilogram—made of platinum. From Aldous's *Course of Physics*. (Macmillan.)

You should bear in mind that in metric measures.

milli-	means	thousandth.
centi-	„	hundredth.
deci-	„	tenth.
deka-	„	ten times.
hekto-	„	a hundred times.
kilo-	„	a thousand times.

By putting these words in front of the word metre, litre, and gram, all the metric measures of length, volume, and mass are obtained, as shown in the following table:

	Length.	Volume.	Mass.
$\frac{1}{1000}$	Milli-metre	Milli-litre	Milli-gram
$\frac{1}{100}$	Centi-metre	Centi-litre	Centi-gram
$\frac{1}{10}$	Deci-metre	Deci-litre	Deci-gram
1	Metre	Litre	Gram
10	Deka-metre	Deka-litre	Deka-gram
100	Hekto-metre	Hekto-litre	Hekto-gram
1000	Kilo-metre	Kilo-litre	Kilo-gram

You see from this that what you have learnt to call the metric system of weights and measures is much simpler than ours, and the children in countries where it is used have not to learn so many different tables as they have in England when they begin "weights and measures" sums.

The Principle of the Balance.

EXPERIMENTAL WORK.

37. *The Principle of the Balance.*—(*a*) Balance a light stiff lath upon an edge of a triangular block, or better, make a hole through a point above its centre so that the lath will turn easily upon a stout nail fixed in a wall or blackboard. Hang a mass by means of a piece of thread upon the lath at any convenient distance on one side of the pivot, or fulcrum, as it is termed, and balance it with a mass of the same amount on the other side. *The distance of the masses from the fulcrum will be found the same in each case.*

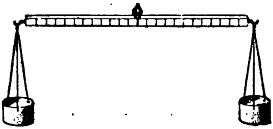


FIG. 36.—Equal masses balanced.

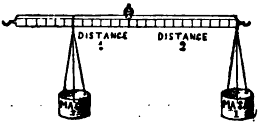


FIG. 37.—Unequal masses balanced.

(*b*) Using the same lath supported on the nail at its middle point, hang over it, at equal distances from the support, two pans (which you can make out of pill boxes and cotton), one on each side of the support. Put a mass of 20 grams in one pan and ascertain how many grams must be put into the other in order that the lath may remain horizontal, or as we say, *be in equilibrium.* It is found that *when the pans are at equal distances from the support there is equilibrium when the masses are equal.*

(*c*) Repeat the last experiment, but while keeping the pan with the 20 grams in it in the same position, shift the other pan and find how many grams must be put into it to bring about equilibrium. Do this with the movable pan in a variety of positions and show that when the lath is balanced,

$$\begin{array}{c}\text{Mass on}\\ \text{one side}\end{array} \times \begin{array}{c}\text{Distance}\\ \text{from fulcrum}\end{array} = \begin{array}{c}\text{Mass on}\\ \text{other side}\end{array} \times \begin{array}{c}\text{Distance}\\ \text{from fulcrum.}\end{array}$$

38. *The Balance.*—(*a*) Uncover the balance and identify the different parts by reference to Fig. 38. Raise the beam, AB, of the balance, off the supports by turning the handle C. Notice whether the pointer F swings equally on both sides of the middle of the scale G: if it does the balance is ready for use; but if not, let down the beam and turn the small screw at B, then try again. Repeat this adjustment until the swings to right and left are equal.

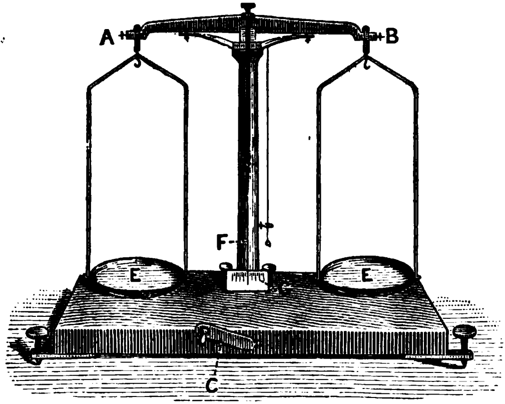


FIG. 38.—The Students' Balance.

(*b*) Put some shot in a watch-glass, and place it in the *left-hand pan*, E, of the balance. Examine your box of weights, and, selecting a weight which you estimate to be about the same as the shot, take hold of it *with the forceps* and place it in the *right-hand pan* (the weights should always be placed in this pan). Now slightly raise the beam to see whether the estimated weight is nearly equal to the mass of the shot. If the weight appears a little below what is wanted, pick up, with the forceps, the next heaviest weight in the box, and try it in the pan with the other. If the two together are too heavy, take out the smaller weight and put in the one below it, and so on, adding one weight after the other, *without missing any*, until you find the correct weight. When you have completed the weighing, write down and add up the weights that are missing from their places, and check the figures as you put each weight back in its place.

(*c*) To become familiar with the process of weighing, find the mass of half-a-crown, a shilling, and other suitable bodies.

(*d*) Find the mass in grams, &c., of an ounce weight.

Masses are determined by means of the Balance.—Though the reader may have seen the spring balance in use among hawkers in the country, it is not in very common use. The instrument generally used for the purpose of estimating masses is the **balance** or **pair of scales.** This simple apparatus is best understood with the help of the simple experiments you have performed and which have taught you that when equal masses are hung from points on a lath supported at its centre, then, when the lath is at rest in a horizontal position, or is in a condition of equilibrium, the distance of the masses from the fulcrum or pivot will be found the same in each case. Similarly, when the pans are at equal distances from the supports there is equilibrium only when the masses are equal. When unequal masses are at different distances from the fulcrum, there is equilibrium only when

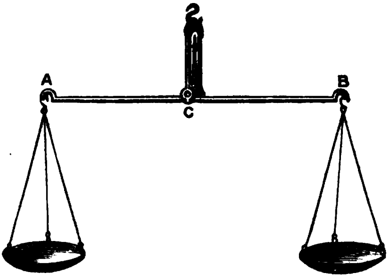


FIG. 39.—A simple balance, or pair of scales.

$$\begin{array}{c}\text{Mass on}\\ \text{one side}\end{array} \times \begin{array}{c}\text{Distance}\\ \text{from fulcrum}\end{array} = \begin{array}{c}\text{Mass on}\\ \text{other side}\end{array} \times \begin{array}{c}\text{Distance}\\ \text{from fulcrum.}\end{array}$$

The Balance.—The form of balance shown in Fig. 39 is evidently similar in principle to the supported lath with pill boxes. This kind of balance is good enough for ordinary purposes, but when exact weighings are wanted, a better form, such as that already described (Fig. 38) is used. All the parts in this balance are very carefully made, and the greatest possible pains are taken to have very delicate supports and accurate adjustments. Instead of the wooden lath described just now, a brass beam is employed. This is supported at its middle line on a knife edge of hard steel, which, when the balance is in use, rests on a true surface of similar steel. The hooks to which the pans are attached are likewise provided with a **v**-shaped groove of hard steel, which also, when the balance is in use, rests upon knife edges on the upper parts of the beam. To the middle of the beam is attached a pointer, the end of which moves in front of an ivory scale, fixed at the bottom of the upright which carries the beam. When not in use, the beam and hooks are lifted off the knife edges by turning a handle.

The Weight of a Body is not determined by an ordinary Balance.—The spring balance and not a pair of scales, must be used to determine the weight of a mass at any place, because by means of the latter apparatus all we do is to make a comparison between the weight of an unknown and that of a known mass. Though the *weight* of the known mass (say the 50 gram weight out of the box) varies from place to place, its mass remains constant, and what we determine when we effect a weighing with the balance is the *mass* of the body experimented upon. If we could attach the 50 gram weight to a very sensitive spring balance and carry it from the equator to the pole, we should find, as we have already stated, that its weight as recorded by the spring balance would vary continuously. We can thus estimate the equality of masses by the equality of their weights; the weight of the body the mass of which is to be determined must, when the balance is in equilibrium, be equal to that of the known mass, and consequently we can argue that their masses are equal. **By the balance we measure the mass of a body, whereas a spring balance enables us to determine its weight at a given place.**

CHIEF POINTS OF CHAPTER III.

Mass is the amount of matter in a body, its **weight** is the force with which the thing tries to get to the earth. The weight of a given mass varies from place to place.

The **Imperial Standard Pound Avoirdupois** is the amount of matter contained in a lump of platinum of a certain size which is kept at the Exchequer Chambers.

The metric standard of mass used in scientific work is the **Gram**; but in everyday use the kilogram, which is equal to a thousand grams, is employed.

A **Gram** is the mass of pure water which will exactly fill a cubic centimetre at a temperature of 4° C.

The same prefixes are used to designate the multiples and sub-multiples of the gram as are used in the case of the metre.

1 gram = 15·4 grains; 1 kilogram = 2·2 lbs. Av.; 1 lb. Av. = 0·46 kilogram.

Masses are determined by means of the Balance.—It is found that when the pans of the balance are at equal distances from the support, there is equilibrium when the masses are equal.

The weight of a body is not determined by an ordinary balance. By the balance we measure the mass of a body, whereas a spring balance enables us to determine its weight at a given place.

QUESTIONS ON CHAPTER III.

1. Define the *mass* and *weight* of a material body, carefully distinguishing between the terms.

2. Give the British and metric measures of mass.

3. State Newton's law of gravitation, explaining clearly the rule of inverse squares.

4. What is a spring balance and what can be measured with it?

5. Explain fully what different readings, if any, are given by a spring balance in the following circumstances and account for them as far as you can:

(*a*) When a spring balance carrying a given mass is taken from the equator to the north pole.

(*b*) When the same balance is carried down a deep mine.

(*c*) When the balance is taken to the summit of a high mountain.

6. Describe an instrument for determining the mass of a material body and explain how it is used.

7. What particulars about a given mass could you determine (*a*) by using a spring balance, (*b*) by means of a pair of scales?

CHAPTER IV

DENSITY AND ITS MEASUREMENT

Meaning of Density.

EXPERIMENTAL WORK.

39. *Meaning of Density.*—(*a*) Determine, by means of a balance, the mass of each of the cubic centimetre solids supplied, and record the results thus:

Grams.

Mass of the cubic centimetre of wood (oak) = 0·82 = $\frac{17}{20}$
" " " lead = 11·35 = $11\frac{7}{20}$
" " " cork = 0·24 = $\frac{6}{25}$
" " " marble = 2·84 = $2\frac{21}{25}$

(*b*) Counterpoise two small bottles of the same size. Fill one with water and the other with methylated spirit. Notice that the bottle of water is heavier than the bottle of spirit, though the volume of each liquid is the same.

(*c*) Place a glass vessel in one pan of the balance, and counterpoise it with shot or small nails in the other pan. Measure out 100 cubic centimetres of water into the glass vessel, and find the mass of the water in grams. Determine the mass of one cubic centimetre by dividing this number by 100. It will be found that the mass of one cubic centimetre is one gram very nearly. It would be exactly if the water were at a certain temperature.

(*d*) A convenient way to add or take away small quantities of liquid is by means of a pipette, used as shown in Fig. 40.

(*e*) Counterpoise a pint measure or bottle with some sheet lead. Fill the bottle with water, and place metal weights in the opposite pan to balance it. Notice that the size of the metal is much less than the size of the pint of water (Fig. 41).

The Meaning of Density.—If different solids are obtained of the same size or volume, every one knows they will have different masses. Suppose, for instance, we determine the mass of a cubic centimetre of wood, lead, cork, and marble, one after the other. The lead will be found to have the greatest mass, or be heaviest, the marble will come next, and then will follow the wood and cork in this order. We thus find that equal volumes of these different solids have different masses.

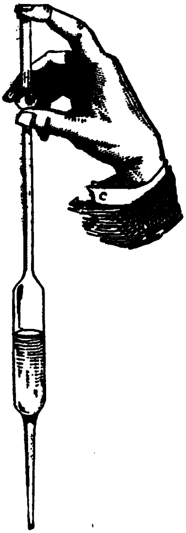


FIG. 40.—Use of a pipette.

By filling two bottles of the same size with different liquids, it can also be shown that equal volumes of different liquids have different masses (Fig. 42). And when different gases are compared in the same way, equal volumes of these, too, are found to have different masses.

Or, if we compare the size of a pint of water with that of one and a quarter pounds of iron, we find that, though as shown by weighing the masses of these things are equal, yet their sizes are very unequal. Hence we may say that equal masses of iron and water have very different sizes.

Two facts which should never be forgotten are taught by experiments of this kind. They are:

1. Lumps of different substances of the same size or volume may have unequal masses.
2. Lumps of different substances which have equal masses may have very different sizes or volumes.

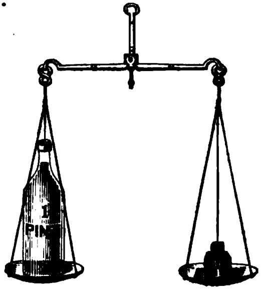


FIG. 41.—The mass of a pint of Water is a pound and a quarter.

It is usual to speak of these facts by saying that things have different **densities**. Referring again to an example we have already used, a pound of feathers or cotton-wool has exactly the same mass as a pound of lead, but, as you know, both the feathers and cotton-wool take up much more room, or have a larger volume, than the piece of lead (Fig. 43). The matter in the lead must be packed more closely than in the cotton-wool, which accounts for it taking up less room. The shortest way of saying all this, and the way in which you must express it for the future, is to say that lead is **denser** than either cotton-wool or feathers.

If the size of a thing the mass of which is great is very little, then it is called a **dense** thing, or is said to have a **high density**. If, on the other hand, the size of a thing is very great and its mass very small, it is said to have a **low density**. Lead is a substance with a high density, because, as you know, a small piece of it has a large mass. Pith and cork, on the contrary, have a low density, because a very large lump of either of them has a small mass.

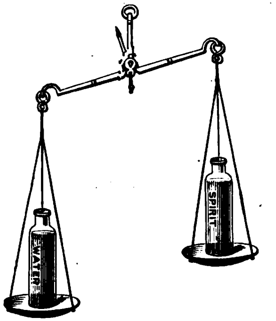


FIG. 42.—Equal volumes may have unequal masses.

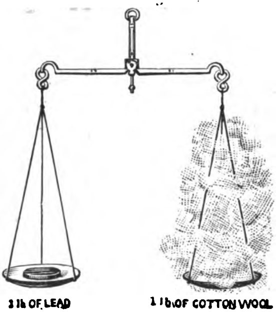


FIG. 43.—Unequal volumes may have equal masses.

How Densities are compared—It is easy to compare densities when lumps of exactly the same size are used. Since the volumes are the same, it is quite clear that the thing with the greatest mass is the densest, and that which has the smallest mass is the least dense, so that we can compare the densities of these things by their masses. If we arrange them in order, putting the heaviest at the top, thus—

lead,
marble,
wood,
cork

we can say that lead is denser than marble, marble than wood, and so on. Moreover, the densities of these things having the same size are in the same proportion as their masses.

Standard of Density.—But to compare densities it is better to have a standard, just as we have a standard of length, the yard, with which to compare other lengths ; or a standard of size with which to compare other sizes. The density of water at a certain fixed temperature is taken as the standard. [This temperature is called four degrees centigrade, and written 4°C., which you will understand after you have studied the thermometer.]

The mass of one cubic centimetre of water at 4° C. is one gram, and its density is taken as the standard of density, and is called 1. Similarly, a substance, the mass of a cubic centimetre of which is two grams, would be said to have a density of 2, for it must contain twice as much matter as water does, packed into one cubic centimetre. The mass of a cubic centimetre of quicksilver is $13\frac{3}{5}$ (13·6) grams, *i.e.* it contains $13\frac{3}{5}$ times as much matter in one cubic centimetre as there is in one cubic centimetre of water. Its density is therefore $13\frac{3}{5}$ or 13·6.

Density is the Mass of a Unit Volume of a Substance. It follows from this definition that if the volume of a body is multiplied by its density, we shall obtain its mass

$$\textbf{volume} \times \textbf{density} = \textbf{mass}$$

$$\text{or, density} = \frac{\text{mass}}{\text{volume}}$$

In using this relation between the volume and mass care must be taken to use the proper units. In all scientific work it is customary to adopt the cubic centimetre and gram as the units of volume and mass respectively.

The ratio of the mass of *any volume* of a substance to the mass of the same volume of water it equal to the **relative density** of the substance, or, as it is frequently called, the **specific gravity**.

Density of Liquids.

EXPERIMENTAL WORK.

40. *To find the Density of Liquid.*—(*a*) Clean and dry a bottle having a mark across the neck. Counterpoise the bottle with a pill

box containing very small nails or lead foil. Now fill the bottle with water up to the mark, and find, by weighing, the mass of the water.

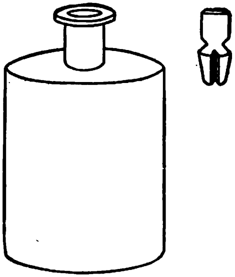


FIG. 44.—A Bottle with a groove in the stopper, for determining relative density.

Empty out the water and fill up to the mark with the liquid the density of which is required, such as methylated spirit or milk. As before, find by weighing the mass of spirit or milk in the bottle. The masses of equal volumes of the two liquids are thus obtained.

(*b*) Procure a small bottle, or medicine phial, with a glass stopper having a groove, made by means of a file along the part which fits in to the bottle (Fig. 44).

A groove of this kind permits liquid to escape when the stopper is put into the neck of a bottle full of liquid. Use the bottle to determine the masses of equal volumes of two different liquids.

(*c*) Make a **U**-tube by bending a piece of glass tubing, or by connecting two pieces of tubing of equal bore with a piece of india-rubber. Mount upon a strip of board.

Pour quicksilver into one of the branches of the **U**-tube until it reaches a horizontal line drawn on the board (Fig. 45).

Now introduce water into one of the tubes, and notice that the mercury on which the water rests is pushed down; afterwards introduce enough water into the other tube to bring the mercury back to its original level. By measuring you find the length of each column is the same. Repeat the experiment with different quantities of water.

(*d*) Remove the water and dry the tubes, and see that the mercury is up to the mark. Nearly fill one of the tubes with some liquid, such as methylated spirit, and balance it with water introduced into the other tube. Measure the lengths of the columns of liquid.

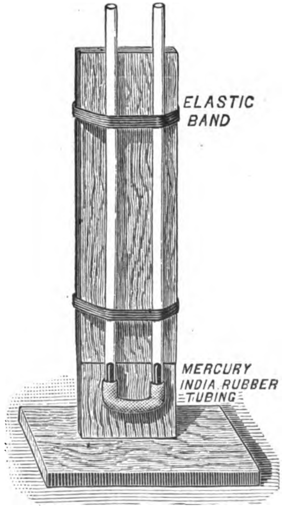


FIG. 45.—An arrangement for balancing columns of Liquid. Mercury is in the bend of the tube, up to the line on the upright board.

(*e*) Connect two glass tubes with a three-way tube as shown in Fig. 46. Let the lower ends of the glass dip into different liquids; then apply suction to the short tube at the top, and when the liquids have risen to a convenient height close the clip upon the india-rubber. Measure the height of the liquid in each tube above the level of the liquid below. The heights are inversely proportional to the densities.

Experimental Determination of Density of Liquids.—Since we only have to be quite sure that the volume of the water and the other substance are exactly the same in order to compare their densities at once, it is a very easy matter to find the density of a liquid. All we have to do is to take a bottle and scratch a mark on it, and fill it up to this mark with the various liquids, and we shall be quite sure this gives us the same volume of each of the liquids. Or, we can completely fill a bottle with one liquid after another, and so obtain equal volumes of them. A convenient way to do this is to use a bottle like the one shown in Fig. 44 having a stopper with a groove cut on it, or a hole bored through it. When such a bottle is filled with a liquid, and the stopper is put in, some of the liquid passes up through the groove to make room for the the stopper. A bottle of this kind may be named a **relative density bottle.**

Suppose the mass of water in a relative density bottle was found to be 50 grams, and the mass of the same volume of methylated spirit was found to be 40 grams. Then these numbers show the relative densities of the two liquids, and as we take the density of water as the standard or unit, the density of the spirit is equal to 40, divided by 50. It is thus seen that the relative density of spirit is represented by the fraction $\frac{40}{50}$ or $\frac{4}{5}$, which as a decimal fraction is 0·8.

The density of many liquids is greater than that of water. Thus, milk has a density represented by the number 1·03, or $1\frac{3}{100}$, so that equal volumes of water and milk would have masses in the proportion of 100 to 103. In all cases, whether solids or liquids are used in the experiments, we can say

$$\text{Relative density of substance} = \frac{\text{mass of substance}}{\text{mass of equal volume of water}}.$$

Balancing Columns of Water.—A convenient way to balance liquids against one another, and so compare their densities, is by means of a glass tube bent in the form of a **U**.

When we arrange a **U**-tube, as in Fig 45, the mercury in the bend acts just like a pair of scales, and we are able to balance a column of water in one of the upright arms with a column of the same length in the other. We are then able to argue thus: the columns of water are the same size, or have the same volume, and they balance one another, and consequently their masses must be the same; and, finally, since their masses are equal and their volume the same, they must have the same density.

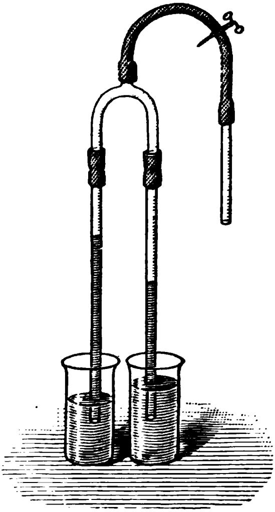


FIG. 46.—Hare's apparatus for comparing the densities of liquids.

Balancing Columns of Different Liquids.—But suppose we put water in one arm of the U-tube, and enough methylated spirit into the other to make the mercury stand at the same height in the two arms.

Here we have a different state of affairs. The column of spirit which balances the column of water will be the longer, hence its size or volume is greater, since the tubes are the same width. But because they balance, their masses must be the same. Which is the denser? Evidently the water is. But how much denser? We can, since the masses are equal, easily calculate this. We may say

$$\text{Relative density of spirit} = \frac{\text{length of water column}}{\text{length of spirit column}}.$$

This is a very good way to compare the densities of liquids.

The Principle of the Mercurial Barometer.

EXPERIMENTAL WORK.

41. (*a*) Procure a barometer tube and fit a short piece of india-rubber tubing upon its open end. Tie the free end of the tubing to a glass tube about six inches long open at both ends. Rest the barometer tube with its closed end downwards and pour mercury into it (being careful to remove all air bubbles) until the liquid reaches the short tube. Then fix the arrangement upright as in Fig. 47. The mercury in the long tube will be seen to fall so as to leave a space of a few inches between it and the closed end. The distance between the top of the mercury

column in the closed tube and the surface of that in the open tube will be found to be about thirty inches.

The Mercurial Barometer—The instrument used in the last experiment is evidently similar to the U-tube. Referring to Fig. 47 it is clear that there is a column of mercury supported by some means which is not at first apparent, or else the mercury would sink to the same level in the long and the short tube, for we know that liquids find their own level. If a hole were made in the closed end of the tube this would immediately happen. There will be no difficulty from what has been already said, in understanding that the column of mercury is kept in its position by the weight of the atmosphere pressing upon the surface of the mercury in the short open tube. The weight of the column of mercury and the weight of a column of the atmosphere with the same sectional area is exactly the same; both being measured from the level of the mercury in the short stem of the apparatus shown in Fig. 47, the mercury column to its upper limit in the long tube, the air to its upper limit, which, as will be seen, is a great distance from the surface of the earth. If for any reason the weight of the atmosphere becomes greater, the mercury will be pushed higher to preserve the balance; if it should become less, then similarly the amount of mercury which can be supported will be less, and so the height of the column of mercury is diminished.

The height must in every case be measured above the level of the mercury in the tube or cistern open to the atmosphere. In the arrangement shown in the accompanying illustration, a line is drawn at a fixed point O, and the short tube is shifted up or down until the top of the mercury in it is on a level with the line.

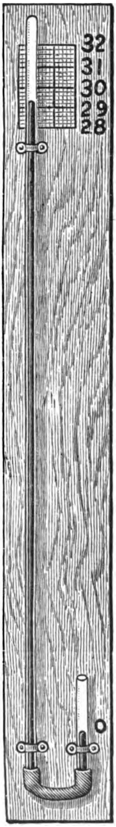


FIG. 47.—To explain the principle of the Barometer.

The student will now understand why it is so necessary to remove all the air bubbles in the last experiment. If this were not done, when the tube was inverted the enclosed air would rise through the mercury and take up a position in the top of the tube above the mercury. The reading would not then be thirty inches, for instead of measuring the whole pressure of the atmosphere, what we should really be measuring would be the difference between the pressure of the whole atmosphere and that of the air enclosed in the tube. In a properly constructed barometer, therefore, there is nothing above the mercury in the tube except a little mercury vapour.

An arrangement like that described constitutes a **barometer**, which we can define as **an instrument for measuring the pressure exerted by the atmosphere.**

Some Things sink, others float in Water.

EXPERIMENTAL WORK.

42. *Some things sink, others float in water.*—Fill a fish-globe or finger-bowl with water, and carefully place lumps of different things, *e.g.*, pieces of lead, iron, oak, pine, and cork, one after another, into the water. Observe that (1) some sink and others float, (2) of those which float some sink further into the water than others. Take the objects which sink in water and place them in mercury. Notice that they float.

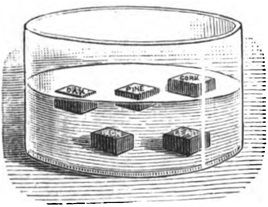


FIG. 48.—When substances are denser than water they sink in water; and if less dense, they float.

43. *Volume of Solids which sink determined by Displacement of Water.*—(*a*) Partly fill a glass cylinder, divided into cubic centimetres (Fig. 49), and record the level of the water therein. Drop in a cubic centimetre lump of a solid which sinks, and again read the level of the water; put others in in succession, recording the level of the water after each such addition. It will be found that the level increases by one cubic centimetre in each case.

(*b*) Take any solid, such as a glass stopper or a marble, and place it gently in water contained in the graduated glass cylinder. Read the level of the water before and after dropping the solid in; the difference between these readings will give you the volume of the solid in cubic centimetres.

44. *Volume of Water displaced by Solids which float.*—(*a*) Obtain a rectangular rod of wood, 1 square cm. in section and about 15 cm. long, with lines around it 1 cm. apart. Gouge a small piece of the wood out of one end, and put lead into the hole; flatten the end by filling in with wax.

Put some water in the graduated jar and notice its level. Find the mass of the rectangular rod, and then place it in the jar with the leaded end downwards. Notice how many cubic centimetres of the rod are immersed, and also how many cubic centimetres of water are displaced (Fig. 50). Since the mass of 1 cub. cm. of water is 1 gram, the number of cubic centimetres of water displaced is also the mass in grams of the water displaced. This mass will be found equal to the mass of the whole rod.

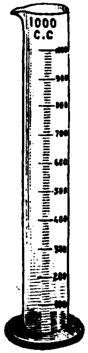


FIG. 49.—A graduated glass cylinder used in the determination of volumes.

(*b*) Fill the divided glass cylinder with water up to a certain mark. Notice the level of the water.

Draw lines at equal distances apart across a narrow strip of paper and fix the paper inside a test-tube, as in Fig. 51. Float the test-tube in water in the graduated jar and put mercury or shot into it until a certain mark upon the strip of paper inside it is on a level with the surface of the water. Notice the number of cubic centimetres of water displaced when the test-tube is thus immersed.

Then take out the test-tube, dry it, and determine its mass together with the mercury it contains. The total mass of the test-tube and contents will be found equal to the mass shown by the number of cubic centimetres of water displaced. Repeat the experiment with the test-tube immersed to a different mark.

Float the test-tube and mercury in spirits of wine and milk in succession. Notice that in the former case it sinks deeper than the mark, while in the other not so deep.

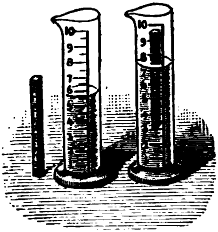


FIG. 50.—The number of cubic centimetres in the part of the rod under water is equal to the number of cubic centimetres of the water displaced.

(*c*) Place the loaded test-tube or a hydrometer (1) in milk, (2) in water, (3) in a mixture of milk and water. Observe the depth to which it sinks in each case. (Fig. 52).

Volume of Water displaced by Bodies placed into it.—If we put water into a narrow glass cylinder, and then add lumps of material of such size and shape that they will go into the vessel easily, we can, by first making a mark on the cylinder at the level of the water and then dropping in the things one at a time, show that, no matter whether they sink or float, the water stands higher when the solids are in it than they did before. Or, as it is usually stated, the solids in every case **displace** a certain amount of water. How much water is thus displaced? Evidently the amount depends upon the volume of the part of the solid under water.

How to determine the Volume of an Irregular Solid.—If a solid one cubic centimetre in size sinks in water it pushes aside one cubic centimetre of water to make room for itself. If its size is two cubic centimetres, it makes two cubic centimetres of water rise above the level the water had at first. Whatever the size of the solid it must have room, and this room is obtained by displacing an amount of water of exactly the same size.

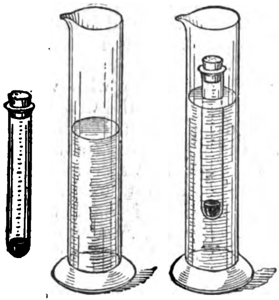


FIG. 51.—The mass of the test-tube and contents is equal to the mass of water displaced.

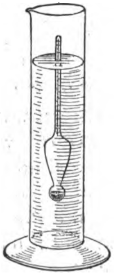


FIG. 52.—An instrument for determining the density of a liquid by flotation.

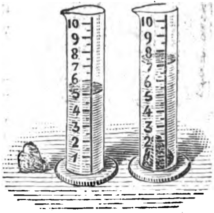


FIG. 53.—The rise of level of the water when the stone is put in shows the volume of the stone.

This is a very useful fact to remember. For suppose you wish to find the volume of a stone having an irregular shape. It would be difficult to do this by measuring the stone, but the stone could be placed in a vessel of water and the rise of level produced by it noticed. The water displaced could then be poured into a cubic inch box or into a cubic centimetre box, and the number of cubic inches or cubic centimetres could be thus found. Or, we could get a glass measure having cubic inches or cubic centimetres marked upon it, and pour the displaced water into it. But the best plan of all is to use a vessel having cubic centimetres marked upon it. Water can be put in such a vessel up to a certain mark, and the number of cubic centimetres of water displaced by the solid can be seen at once by noticing the number of divisions between the levels of the water before and after the solid is put in.

Water Displaced by Solids which float.—You have learned that a solid which sinks in water or any liquid displaces a volume of liquid equal to its own volume. When a solid floats, the case is slightly different. Part of the solid is in water and part out of the water, and, of course, only the part immersed is pushing the water aside in order to make room for itself. **In the case of a floating object, therefore, the volume of liquid displaced is equal to the volume of the part of the solid below the surface.**

What decides the Depth at which an Object floats in water?—When any object is floating in water, a certain volume of it is under water and a certain volume is above the surface. You know very well that the depth at which it floats depends upon its heaviness, or, in more exact words, upon its density. A rod of heavy wood sinks deeper in water than a rod of light wood of the same size. The water displaced by the heavy wood has therefore a greater volume, and consequently a greater mass, than that displaced by the light wood. But there is one important fact which applies to both cases, and should be kept well in mind. It is that **the mass of the water displaced by the immersed part of a floating object is equal to the whole mass of the object.** If therefore you are asked how far does an object which floats sink into water, the answer is—it goes on sinking until it has displaced an amount of water the mass of which is equal to that of the whole mass of the floating object.

How far will an Object sink in other Liquids in which it floats?—Since the depth at which an object floats in water is decided by the rule we have just learnt, namely, that it goes on sinking until the mass of the water displaced by the immersed part of it is equal to the mass of the object itself, we have a ready way of deciding whether an object will sink further in another liquid or not so far. If the liquid into which it is put is less dense than water, like spirits of wine, it is clear that to make up a given mass we shall want more of the liquid. Consequently, to make up a mass equal to the mass of the floating body, the object will have to sink further into the spirit than into the water. If, on the other hand, the object is placed in a liquid such as mercury, which is denser than water, it will not sink so far, because it will not take so much of this denser liquid to have a mass equal to that of the floating body.

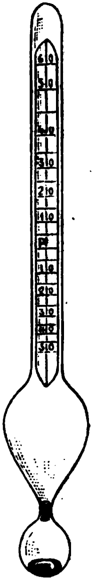


FIG. 54.—A hydrometer for determining the quality of milk. It is called a lactometer.

The Lactometer.—The construction of a simple instrument, called the *lactometer*, is based upon these conclusions. It is a form of hydrometer employed for measuring the density of milk. When placed in pure milk a lactometer should float with the mark P (Fig. 54) on a level with the surface of the liquid. In a mixture of milk and water the lactometer floats with some other division level with the surface of the liquid. Thus, in milk 10 per cent. below the average density, the 10 above the P mark is level with the surface.

An experienced observer is, therefore, able from the readings of a lactometer to tell whether a sample of milk has a correct density, or whether it is heavier or lighter than it should be. At the same time it must be clearly understood that it is not possible to decide at once from the reading of a lactometer whether a sample of milk has been adulterated or not. There are other considerations to be taken into account.

The Principle of Archimedes.

EXPERIMENTAL WORK.

45. *Principle of Archimedes.*—(*a*) Suspend a metal cube, or any other fairly heavy object, from a spring balance, and notice the reading of the balance. This indicates the weight of the object in air. Immerse the cube in water, as in Fig. 55, and again notice the reading of the balance. It is less than before, and the loss of weight shows the buoyant power or upward pressure of the water.

(*b*) Find the volume of the cube, or other object used in the last experiment, by noticing the volume of the water it displaces in the graduated jar.

Hang the object from one pan of the balance, as shown in Fig. 56, and determine its mass in grams. Now bring a vessel of water under the pan so that the object is immersed in it, as in Fig. 57. The pan rises. Put gram weights in the pan until the balance sets horizontally as before. You thus find the apparent loss of mass due to the buoyancy or upward pressure of the water. Notice that the number giving this loss in grams is the same as that giving the volume of water in cubic centimetres displaced by the object.

(*c*) If time permits, repeat the experiment with another object, and find again that the number giving its volume in cubic centimetres is the same as that showing the loss of weight (measured as before) when immersed in water.

(*d*) This principle, viz., that when an object is immersed in water it experiences a loss of weight equal to the weight of water displaced, can be convincingly demonstrated as follows:—Suspend an object from the left hand pan of a balance. Place in the short scale pan a small measuring-glass graduated in cubic centimetres. Counterpoise the suspended object and the measuring-glass together. Now pour water into a graduated jar until the jar is about two thirds full. Notice the level. Bring the jar under the short scale pan so that the object is immersed as in Fig. 58. Notice the amount of water displaced. Put water gradually into the measuring-glass by means of a pipette. Equi-

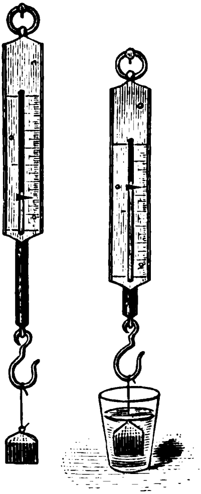


FIG. 55.—The block weighs less when immersed in water than when suspended in air.

librium will be restored when the amount of water added is equal to the amount displaced.

(*e*) Procure a small tin canister about half the diameter of the graduated jar. Put some water into the jar. Notice the level. Place the canister in the water and gradually put shot or small nails into it until it just sinks in the water when the cover is on. Pour the water displaced by the canister into a beaker counterpoised upon a balance; then take out the canister, wipe it, and place it in the other pan of the balance. You will find that the mass of the canister and shot is practically the same as the mass of the water displaced.

(*f*) Repeat the experiment, using another liquid, such as methylated spirit, or turpentine, instead of water.

Buoyancy.—Most people have noticed when in a bath that if there is water enough, and they take hold of no support, the water buoys them up, or they experience a tendency to rise up through the water. It is as if the water resists being displaced and presses the displacing object upwards. In the case of things which float, such as a wooden rod or a lead pencil, you can easily see the results of this buoyancy which the water exerts, by pushing either the rod or pencil down into the water and then letting go, when the solid rises up through the water. Even in the case of bodies which sink, there is the same buoyancy on the part of the water, but it is not enough to float them. The effect which the water has upon such bodies can, however, be

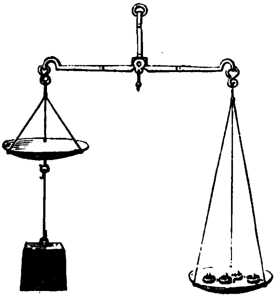


FIG. 56.—Weighing an object in air.

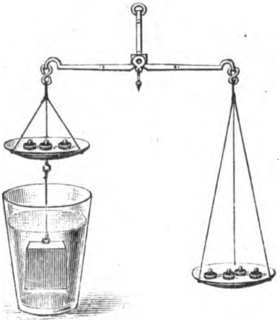


FIG. 57.—The same object weighed in water. Notice that weights are in the short pan to make up for the buoyancy of the water.

seen in the loss of weight which they experience if they are weighed by a spring balance when hanging in water (Fig. 55).

Loss of Weight of Things immersed in Water.—It is easy to prove by experiment that an object weighs less in water than out of it. If a cubic centimetre of lead, or any other heavy material, is hung from a spring balance and then suspended in water, it will be found to weigh the weight of one gram less in water than out. If two cubic centimetres are suspended from the balance, the loss of weight is the weight of two grams. In every case the loss of weight measured in this way is equal to the number of cubic centimetres of the solid immersed in the water. The loss is thus equal to the *weight of the water displaced.* This fact brings us to a highly important conclusion, known after its discoverer as the *Principle of Archimedes.*

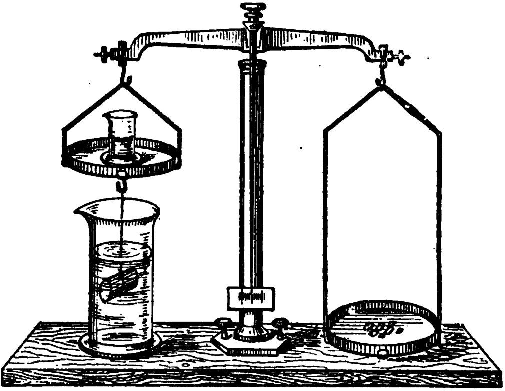


FIG. 58.—When an object is immersed in a liquid it experiences a loss of weight equal to the weight of the liquid displaced by it.

The Principle of Archimedes—When a Body is immersed in Water it loses Weight equal to the Weight of the Water displaced by it.—If the body be immersed in any other liquid, then, the loss of weight is equal to the weight of an equal volume of that liquid. It does not matter what substance a thing is made of; the amount of loss of weight depends upon the *volume* of the part immersed and not upon the material.

This principle will enable you to understand many interesting facts. For instance, a ship made of iron, and containing all kinds of heavy things, is able to float in water although the material of which it is made is denser than water. This is because the ship and all its contents only weigh the same as the volume of the water displaced by the immersed part of the hull. Or, the ship as a whole weighs less than a quantity of water the same size as the ship would weigh.

Now, too, we can see why some solids float and some sink. When an object weighs more than an equal volume of water it sinks. When an object weighs less than an equal volume of water it floats. When an object weighs the same as an equal volume of water it remains suspended in the water.

A balloon rises in the air because the gas in the balloon, together with the bag and tackle, weighs less than an equal volume of air. If the balloon were free to ascend it would rise to a height where its weight would be equal to the weight of an equal volume of air.

Relative Density of Solids.

EXPERIMENTAL WORK.

46. *Determination of Density of Solids.*—(*a*) Suspend the solid the density of which you are going to determine, to one side of the balance, letting it hang in an empty beaker standing upon a platform, H, H, as shown in Fig. 59. By weighing find the mass of the object. Then pour water into the beaker, and find the apparent mass of the object when immersed in water. By subtracting the number thus found from the mass of the object in air, determine the loss in weight of the solid when suspended in water.

(*b*) Another plan of determining the apparent mass of an object in water was explained in the last section (Fig. 57).

This loss of weight equals the weight of a volume of water equal to the volume of the solid. We can therefore write:

$$\text{Relative density of solid} = \frac{\text{Weight of the solid in air}}{\text{Its loss of weight in water}}.$$

How the Relative Density of a Solid is determined.—Until the Principle of Archimedes has been studied, it is not possible to understand the steps by which the relative density of a solid is obtained. But now that you have found out that when a body is immersed in water it loses weight equal to the weight of the water displaced by it, you are in possession of all the information necessary for determining the density of a solid compared with water.

All we want to know is :

1. The mass of the object ; this we can determine by weighing it in air.
2. The mass of an equal volume of water.

And the Principle of Archimedes enables this to be done in the following manner :

The object is suspended by means of a fine thread, from one side of the beam of a balance in such a way that it is completely immersed in water. Then by weighing it is found that the mass appears less than when hanging in air. This is because it loses weight in the water. The buoyancy of the water acting upwards overcomes part of the pull of the earth downwards. The difference in the mass of the object in air and its apparent mass when immersed in water gives the mass of a volume of water equal to the volume of the object. From these numbers the density of the solid compared with water as a standard can be at once calculated.

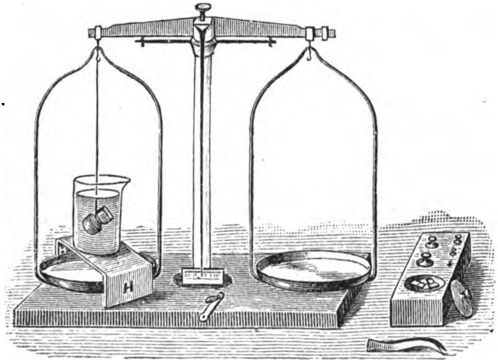


FIG. 59.—How to find the weight of an object suspended in water.

$$\left.\begin{array}{l}\text{Relative density of the}\\ \quad\text{solid}\end{array}\right\} = \frac{\text{Mass of the object in air}}{\text{Mass of an equal volume of water}}.$$

Another way to find the Mass of an Equal Volume of Water.—To find the mass of an equal volume of water, the object could be placed in a graduated jar and the amount of water displaced could be taken out and its mass determined by weighing. Or, if the number of cubic centimetres of water displaced is observed, the same number shows the mass of the displaced water in grams.

Example.—A piece of lead was found to have a mass of 100 grams in air, and when suspended in water its mass appeared to be 90 grams. What is its density compared with water?

What must be done with these numbers to find out the density of the lead compared with water? We want to know two facts, —first, the weight of the object in air. The mass is found by weighing, and the weight is directly proportional to this. Secondly, we want to know the loss of weight in water, as this gives the weight of an equal volume of water. The loss of weight is obtained by subtraction, thus:

$$\begin{aligned}\text{Loss of weight} &= \left.\begin{matrix}\text{The weight of}\\ \text{the lead in air}\end{matrix}\right\} - \left\{\begin{matrix}\text{The weight, or its}\\ \text{apparent mass, in water}\end{matrix}\right.\\ &= \text{weight of 100 grams} - \text{weight of 90 grams}\\ &= \text{weight of 10 grams.}\end{aligned}$$

$$\therefore \text{Density of the lead} = \frac{100}{10} = 10.$$

Since the density of this piece of lead is 10, one cubic centimetre of it will have a weight equal to that of 10 grams. What is the volume of the piece of lead used in the example? Evidently, since its weight is equal to that of 100 grams, its volume must be ten cubic centimetres.

Chief Points of Chapter IV.

Density.—Equal volumes of different substances have different masses.

Relative density or *specific gravity* is the ratio of the mass of any volume of a substance to the mass of an equal volume of water.

$$\text{Relative density} = \frac{\text{mass of substance}}{\text{mass of equal volume of water}}.$$

$$\text{Also, Relative density} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}.$$

Relative Density or Specific Gravity Bottle.—This is a small glass flask holding about 50 grams of water. It is provided with a nicely-fitting ground stopper, which is in the form of a tube with a very small hole through it. Its use depends upon the first of the preceding equations.

Balancing Columns of Liquids.—The densities of two liquids balanced in a U-tube are in inverse proportion to the lengths of the columns. Or, the density of one liquid is less than the density of the other in proportion as its column is longer than the balancing column of the other.

$$\therefore \text{ Relative density of a liquid} = \frac{\text{water column}}{\text{liquid column}}.$$

A Barometer is an instrument used to measure the pressure of the atmosphere.

The Principle of the Action of a Mercurial Barometer.—The column of mercury balances a column of air extending from the surface of the mercury in the cup to the limits of the atmosphere. The action is therefore analogous to balancing columns of different liquids in a U-tube.

When an object floats in a liquid, the volume of liquid displaced is equal to the volume of the immersed portion of the object.

The mass of the liquid displaced by a floating object is equal to the whole mass of the object.

An object which floats in water sinks deeper into a liquid which is less dense than water, and not so deep into one which is denser than water.

Principle of Archimedes.—When a body is submerged in a liquid, it loses weight equal to the weight of the liquid displaced by it.

Expressed differently, the upthrust experienced by an object in water is equal to the weight of the water displaced.

The number of cubic centimetres in an object is also the number of cubic centimetres of water displaced by such an object when it is immersed in water.

QUESTIONS ON CHAPTER IV.

1. Define mass, volume, and density, and state the relation that exists between them.

Suppose you were given two irregular pieces of metal, one of which was gold and the other gilded brass. How would you find out, by a physical method, which piece was gold?

2. Explain why a ship made of iron will float in water, though iron itself is heavier, bulk for bulk, than water?

3. A number of nails are driven into a rough piece of wood, one cubic centimetre of which weighs 0·5 gram. It is required to find the weight of the nails without pulling them out. How could this be done by experiment?

4. A covered tin canister having a volume of 88 cubic centimetres

contains just enough shot to sink it to the top of the cover when placed in cold water. Determine from this information—

(*a*) The weight of the canister and shot:

(*b*) The weight of the water displaced by the canister.

5. Describe an experiment to show that when a solid body is immersed in water its apparent loss of weight is equal to the weight of the water it displaces.

6. Describe the method of determining the specific gravity of a body by weighing it alternately in air and water.

If a body weighs 14·4 grams in air and 12 grams in water, what is its specific gravity?

7. Describe how you would measure the density of a piece of stone, giving a sketch of the apparatus you would employ.

8. Describe a method of determining the specific gravity of a liquid.

9. Explain what is meant by specific gravity. A body of specific gravity 5 weighs 20 grams in air; what will the body weigh when immersed in water?

10. A bottle weighs 2 ounces. When holding 3½ ounces of shot it will just float in water, when holding 3 ounces it will just float in oil, and when holding 3¾ it will just float in brine. Find the specific gravity of the oil and the brine.

11. A piece of metal weighs 19½ grams in air, and 17¼ grams in water. What is its specific gravity?

With what apparatus and in what manner would you find the weight in water?

12. A stone, weighing in air one kilogram, is suspended by a piece of cotton so that it is entirely immersed in water. On attempting to lift the stone out of the water the cotton breaks when the stone is partly out of water. Why is this?

If when the stone is completely immersed the cotton would bear an additional pull equal to the weight of 150 grams, what volume of the stone will be out of the water when the cotton breaks?

13. Explain the statement that "the specific gravity of iron is 7·8." Describe one method of finding this specific gravity.

14. About what height does the mercury column of the barometer generally stand? Explain why the tube must be kept in a vertical position.

What is the effect of introducing two or three drops of water into the space above the mercury? What of making a very small hole in the top of the tube?

CHAPTER V

MEASUREMENT OF TIME, VELOCITY, AND ANGLES.

Units of Time.

EXPERIMENTAL WORK.

47. *The Sun's Apparent Daily Movement.*—Fasten a small rod at right angles to a flat board. Place the board flat on a table so that the rod is vertical. Move a candle in a semicircle above the table, and note the change in the direction and length of the shadow of the rod. Compare the conditions of the experiment with the measurement of the solar day by means of a sun-dial.

48. *Measurement of Time by Pendulum.*—Attach a weight to the end of a cord. Fix the cord in such a way that the pendulum can oscillate freely. Set it oscillating, and notice how long it takes for the pendulum to complete a given number, say twelve, swings. Keeping the cord exactly the same length, attach a heavier weight and repeat the experiment. The time of swing remains unaltered. Keeping any one weight, observe the time taken to complete twelve swings when the length of the cord is varied. It will be seen that the time of swing varies with the length of the cord. Notice also that whether the pendulum makes a wide oscillation or a very small one, the time taken is the same.

49. *The Seconds' Pendulum.*—Vary the length of the string until there are thirty swings in half a minute. You have prepared a seconds' pendulum. Measure the distance from the point of suspension to the centre of the weight; it will be found to be about 39·2 inches.

The Earth's Rotation.—The apparent daily motion of the sun and stars across the sky is a direct consequence of the earth's rotation on its axis. The sun appears to regularly go through certain periodic changes of position. It rises, travels higher and higher into the sky, reaches its highest position, sinks lower and lower, and finally sets. When the sun is at its highest altitude on any day it is due south, and is said to *south* or be *southing*. The interval of time between the sun's highest position on any one day to its corresponding position on the next succeeding day is an **apparent solar day**. These apparent solar days vary in length throughout the year.

Mean Solar Day.—It has been pointed out that the length of days measured by the sun varies throughout the year, hence no single one of these days will do for a convenient standard of time. But if the lengths of all the days in the year be added together, or the length of a year measured by the sun be divided by the number of days in the year, we obtain an interval of time which is always the same. Such a day, which is of course an imaginary one, is called a **mean solar day**. Sometimes the mean solar day will be longer than the solar day, sometimes it will be shorter, and occasionally both days will be of exactly the same length. Solar time is known as *apparent time*, and clock time as *mean time*.

Units of Time.—The mean solar day, that is, the mean interval between two successive southings, or transits of the sun observed at any one place, is subdivided into hours, minutes, and seconds.

In physical measurements the unit of time adopted is the mean solar second, that is, it is founded on the average time required by the earth to make one complete rotation on its axis relatively to the sun considered as a fixed point of reference ; it is the 86,400th part of a mean solar day.

Instruments for Measuring Time.—We need only concern ourselves with the modern contrivances for measuring time, viz., clocks and watches. It will be sufficient to regard these as instruments for measuring intervals of time in terms of the mean solar day to which attention has been directed. In a clock the rate is regulated by means of the pendulum the properties of which have been learnt by the experiments.

If it were possible for the student to perform the experiment, it would be found that the time taken for the pendulum to swing backwards and forwards varies as it is taken from the equator to the poles, on account of the fact that the earth is not exactly spherical in shape. Or, putting the same fact in another way, in order that a pendulum may swing backwards and forwards in the same interval of time, it is necessary to alter the length of the cord in our experiment as we travel from the equator towards either pole. A pendulum of such a length that the distance from the point of suspension to the centre of the bob is 39·139 inches, swinging at Greenwich, completes one swing in a second of time. In a clock we have a mechanical contrivance for maintaining the swinging of a pendulum. We must content ourselves with referring the reader to books on astronomy and horology for an account of the construction of a clock. In watches the place of the pendulum is taken by a carefully suspended balance wheel.

Acceleration.

EXPERIMENTAL WORK.

50. *Acceleration.*—Obtain a smooth board about six feet long having a slight groove cut in it from one end to the other (Fig. 60). Incline the board slightly at one end. Place a marble or other small sphere near the raised end and let it roll down the board. Notice that as it moves how its velocity increases. To show that the space traversed increases every second, fit up a seconds' pendulum and set it in motion. Let the pendulum strike against a sheet of paper or some other object at the end of each swing, so that you can hear when the seconds commence. Now start the marble from a mark upon the board exactly when the pendulum taps the paper on one side. Notice how far the marble has rolled by the time the pendulum taps the paper on the other side. Make a mark at the place reached, and do the same for succeeding seconds until the marble rolls off the board. Measure the length of board traversed by the marble in each second. The distances will be found to increase in proceeding down the board from the starting place.

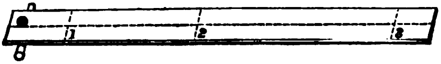


FIG. 60.—A grooved board for experiments to illustrate acceleration.

Definition of Motion.—The word *motion* is meant to convey the idea of *change of place.* The simplest forms of motion are changes in the positions of bodies with regard to one another. When a boy runs down the street he is in *motion*; as regards the houses and lamp-posts he moves. To fully describe the boy's motion it would be necessary to know the *direction* in which he is moving or the *line* along which he runs, and the *rate* or *velocity* with which he travels.

Velocity.—Velocity is, then, **the rate at which a body moves**, or the number of units of length it moves over in a unit of time. Velocity may be either *uniform* or *variable*. In the case of our boy, if during every second through which he moves he travels over a line of five yards in length, we should say he had a *uniform* velocity of five yards a second. But suppose this boy does not move regularly over five yards in every second; he sometimes dawdles, sometimes stops to look at a shop, at other times he puts on a spurt to make up for lost time. How should we describe his motion now? His rate varies from time to time, or his velocity is *variable*, and to describe such a variable velocity it is usual to speak of the velocity *at any instant* as being a certain number of yards per second. Say the boy of our example, moving with a variable velocity, has at a given instant a velocity of eight yards per second. We should mean that he would, if he continued to move at the same rate as he had at the given instant, travel over eight yards in the succeeding second

Average Velocity.—But it is sometimes better to find the *average velocity* of the moving body. Returning to our boy, suppose he travelled 800 yards in 400 seconds; if we divide the first number by the second we obtain the boy's average rate, namely, two yards in a second; this, then, is the rate with which he would have had to travel, if he moved uniformly, in order to complete his journey in the same time.

The **unit of velocity** is the velocity of a point which passes over the unit of length in a unit of time; it is generally taken as being a velocity of one foot per second. Thus a velocity of six means a velocity of six feet per second.

Measurement of Uniform Linear Velocity.—It is a very simple matter to calculate the velocity of a body moving uniformly in a straight line when we know the distance it has travelled, measured in units of length, and the time it has taken to perform the journey, measured in units of time. Thus, if we represent the space it has passed over, measured in units of length, by the letter s, and the time taken, measured in units of time, by the letter t, all that we have to do in order to find its uniform velocity is to divide the number of units of length passed over by the number of units of time taken to complete the distance. Thus:

$$\text{Uniform velocity} = \frac{\text{No. of units of length passed over}}{\text{No. of units of time taken}}.$$

From this equation it will be seen that space traversed (s) = velocity (v) × time (t).

EXAMPLE.—A train, travelling at a uniform rate, completes a distance of 10 miles in 15 minutes; what is its velocity in feet per second?

Answer: 10 miles = (10 × 1,760 × 3) feet = 52,800 feet
15 minutes = 15 × 60 secs. = 900 seconds

∴ since $v = \frac{s}{t}$

$$v = \frac{52,800}{900} = 58\tfrac{2}{3} \text{ feet per second,}$$

or, the train travels at a uniform velocity of $58\frac{2}{3}$ feet in every second.

Acceleration.—An express train starting from a terminus begins to move slowly, and, as the journey proceeds, the rate of motion goes on increasing until it gets its full speed. A stone let fall from a height similarly starts from rest, and as it moves it goes faster and faster until brought to a standstill again on reaching the ground. Or, we might imagine a cyclist starting for a run, and regularly increasing his speed until he could not go any faster. In all these examples the velocity of the moving body has regularly increased and the rate at which the change has taken place is spoken of as *acceleration.*

Acceleration is the Rate of Change of Velocity.—But it may be of an exactly opposite kind to the instances given above. Reverse each of the examples and consider what happens. An express train going at full speed approaches a station and its velocity is regularly diminished until it is brought to rest at the platform. A stone is thrown upwards with a certain velocity, it moves more slowly and more slowly until it comes to rest, and then starts falling. A cyclist travelling at full speed slackens his rate regularly until he comes to a standstill. In all these cases we have examples of an acceleration of an exactly opposite kind to the previous instances, but yet an acceleration. In ordinary language this kind of acceleration is given a name of its own, *retardation.*

Measurement of Uniform Acceleration.—In measuring a regular or *uniform acceleration*, we must know what addition to or subtraction from the velocity of the moving body there has been during each second of its journey. Suppose there is an addition of one foot per second to the velocity of a moving body, and that it has taken one second to bring about this change, we should refer to this as an acceleration of one foot per second in a second, or *one foot per second per second.* An acceleration which increases the velocity is referred to as *positive*, while that which diminishes it is *negative.* The first examples given above are instances of positive acceleration, while when we reverse them they afford cases of negative acceleration.

Unit of Acceleration.—As in every other measurement so, when we wish to measure accelerations, we must have a unit in terms of which we can express the quantity under consideration. **The unit of acceleration is an increase of unit velocity in a unit of time**; it is generally taken as equal to *an increase of velocity of one foot per second per second.* An acceleration of *two units* would thus be an increase of velocity of *two* feet per second per second; similarly, an acceleration of three units equals an increase of velocity of three feet per second per second, and so on for any number of units.

Consequently, to find the velocity at any instant of a uniformly accelerated moving body, all that is necessary is to multiply the number of units of acceleration by the number of units of time for which it has been moving.

Space traversed by a Body moving under the influence of a Constant Acceleration.—The space travelled over by a body in one second is equal to its average velocity, and that travelled over in any given number of seconds is equal to its average velocity multiplied by that number.

The rule for finding the space travelled in a given number of seconds is—multiply half the acceleration (expressed in feet per second per second) by the square of the number of seconds through which the body travels.

By another rule the velocity of a body after it has travelled over a certain distance under the influence of a uniform acceleration can be calculated. The rule is that the square of the body's velocity is equal to twice the product of the acceleration (in feet per second per second) under which it moves into the distance in feet it has travelled over. Proofs of these rules will be found in any book on dynamics or theoretical mechanics.

EXPERIMENTAL WORK.

51. *Combination of Two Velocities.*—Place a wide glass tube along a table near one edge. Let a marble roll through the tube, and as it does so roll the tube across. Suppose a second is taken for the tube to move from its first to its last position, then the positions of the marble at intervals of a tenth of a second are shown in Fig. 61. The marble enters at A and emerges at D; the distance it has travelled in the direction of the length of the table is therefore represented by AB. The distance it has travelled *across* the table is in the same way represented by AC. Construct a parallelogram CABD with lines proportional to CA and AB as sides. The diagonal AD represents the path actually traversed by the marble.

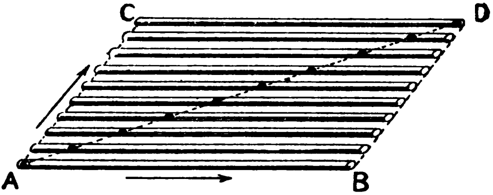


FIG. 61.—To illustrate the combination of two velocities, and the principle of the parallelogram of velocities.

Velocities and Accelerations can be completely represented by Straight Lines.—To completely understand a velocity all we want to know are its magnitude, or the distance travelled in a given time, and its direction. In the same way, we know all about an acceleration if we are aware of its magnitude and the direction of the velocity to which it gives rise. But, as is well known, a straight line can be drawn in any direction and of any length; and we can arrange that its length shall contain as many inches or feet, whichever is more convenient, as there are feet or yards per second of velocity, depending on the way in which we decide to measure our velocities. We can therefore completely represent velocities by straight lines.

Composition of Velocities.—Think of the case of a marble moving along a tube with a uniform velocity, when the tube itself is all the time being uniformly moved across a table. It is evident that since the marble is in the tube it must have the same velocity *across* the table that the tube has; and at the same time it moves along the tube, that is, in a direction at right angles to its former velocity. It has two independent velocities. Similarly, we can think of a ship sailing across the ocean with a man on deck walking from one side of the ship to the other. The man has two velocities. He is moving onwards with the ship at a certain velocity and at the same time he is moving across the ship with another velocity.

But yet a body can only move at any instant in one direction with one definite velocity. How, then, shall we find the actual velocity at any instant in the case of the marble or of the man? The velocity which we want to find is called the **resultant** of the two independent velocities, which are themselves spoken of as **components**. If the two velocities have the same direction, all we have to do is to add them to obtain the resultant, or if they are in opposite directions along the same straight line we subtract them. If they have directions which make an angle with one another, it is clear that the resultant must be somewhere between. Referring to the case of the marble, let OA (Fig. 62) represent by its length the number of inches the marble moves along the tube in a second, and OB the distance moved by the tube, and consequently by the marble in the same time across the table. The arrows give the direction of the movement. Draw BR parallel to OA and AR parallel to OB, thus completing the parallelogram, then the line OR represents the resultant velocity, both in magnitude and direction. In just the same way OA could stand for the ship's velocity and OB for the man's, then OR would represent the direction and magnitude of the man's actual velocity. This principle is called the **Parallelogram of Velocities.** The same

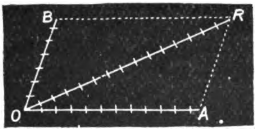


FIG. 62.—Parallelogram of Velocities.

method can be used to represent two accelerations and their resultant.

Measurement of Angles.

EXPERIMENTAL WORK.

52. *Meaning of an Angle.*—(*a*) Procure a pair of dividing compasses and hold one leg in a fixed position. Gradually move the other round, and notice that the inclination of the movable leg to the fixed one regularly increases, or the *angle between them becomes greater.* When the moving leg has been moved completely round it has described a *circle.*

(*b*) Draw a large circle upon a sheet of cardboard, and divide it into 360 equal parts. Cut two narrow strips of card of a length slightly greater than the radius of the circle, and pin one end of each to the centre of the circle (Fig. 63). Show, by placing the strips at different inclinations to one another, the meaning of angular measurement, and the sizes of angles of, say, 30°, 60°, 90°, 120°, &c.

(*c*) Examine a protractor. By its means measure and mark the value in degrees of each of the angles of a pair of set squares.

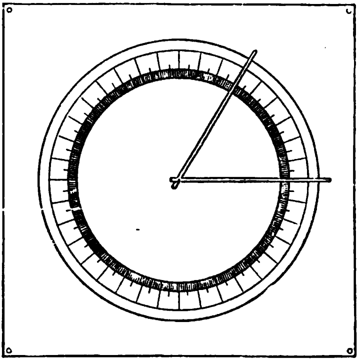


FIG. 63.—Divided circle and movable hands to illustrate the measurement of angles.

(*d*) Construct an equilateral triangle (Euclid I., 1). Using the protractor, measure and record the number of degrees in each of its angles.

Definition of an Angle.—Up to this stage we have referred only to linear measures, and how with these area and volume can be estimated. We must now deal with angles. An angle may be defined as *the inclination of two lines which meet together but are not in the same straight line.*

Definition of a Circle.—The simple experiment with a pair of dividers, 52 (*a*), leads naturally to the definition of a circle, and we can speak of it as *a plane figure bounded by one line called the circumference, and is such that all lines drawn from the centre of the circle to the boundary line are equal.*

From the experiment the student will at once perceive that the moving leg remains the same length during its revolution, and that its point marks out a continuous line which encloses a figure of the nature described in the above definition.

Definition of a Plane.—We have spoken of the circle as a "plane" figure, *i.e.*, one lying in the same plane. A plane is a surface, *e.g.*, the surface of the page on which this is printed is a plane surface. Such a *plane has length and breadth but no thickness, and is such that any two points being taken in it the straight line between them lies wholly in that plane.*

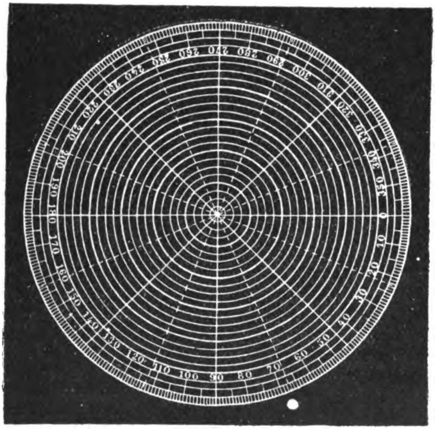


FIG. 64.—The size of an angle does not depend upon the size of the circle upon which it is marked. All circles contain 360°.

Unit of Angular Measurement.—The general plan adopted in measuring angles is to divide a circle into 360 equal parts, and to call each part a *degree* (1°). Thus, a movable hand pivoted at the centre of a circle has traced out an angle of one degree when it has gone round $\frac{1}{360}$th part of a complete revolution. When it has performed one quarter of its journey round, it has made an angle of ninety degrees, or a *right angle*, as it is called.

The minute hand of a watch or clock moves through 360 degrees in an hour, or ninety degrees in every quarter of an hour, and this is true whatever the size of the timepiece. This reveals a very important fact, viz., that the size of an angle is quite independent of the length of the lines between which it is contained or the *arms* of the angle. All circles contain 360 degrees, Fig. 64. All right angles contain ninety degrees, so there are four right angles to every circle. In accurate measurement parts of a degree are measured, and the subdivisions used are that one degree equals sixty minutes, and one minute (1′) equals sixty seconds (60″).

CHIEF POINTS OF CHAPTER V.

The Solar Day is the interval of time between the sun's highest position on any one day to its corresponding position on the next succeeding day.

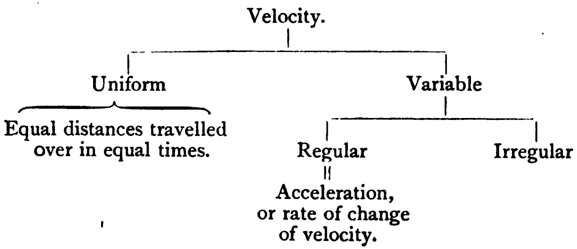
The Mean Solar Day is the quotient obtained by dividing the length of the year measured by the sun by the number of days in the year. Or, it is the average of the lengths of all the solar days in the year.

Units of Time.—In physical measurements the unit of time adopted is the mean solar second, that is, the 86,400th part of a mean solar day. The unit is founded on the average time required by the earth to make one complete rotation on its axis relatively to the sun considered as a fixed point of reference.

The Velocity of a body is the rate at which it moves in unit time. Velocity may be either *uniform* or *variable*. When a body's velocity is uniform it moves over the same distance in every second. When the velocity is variable unequal distances are moved over in equal times.

$$\text{Uniform velocity} = \frac{\text{No. of units of length travelled}}{\text{No. of units of time taken}}.$$

Acceleration is the rate of change of velocity. In measuring uniform acceleration we must know what addition to or subtraction from the velocity of the moving body there has been during each second of its journey.


Velocity.
Uniform
Variable
Equal distances travelled over in equal times.
Regular
Irregular
Acceleration, or rate of change of velocity.

The Unit of Acceleration is an increase of unit velocity in a unit of time. It is generally taken as equal to an increase of velocity of one foot per second per second.

Measurement of Angles. One degree (1°) is $\frac{1}{90}$ of a right angle and $\frac{1}{360}$ of a circle.

60 seconds of arc (60″) = 1 minute of arc (1′).
60 minutes of arc (60′) = 1 degree (1°).
90 degrees = 1 right angle.
4 right angles = a complete revolution.

QUESTIONS ON CHAPTER V.

1. Give a definition of *velocity*, and state how uniform linear velocity is measured.

2. What is the difference between a *solar day* and a *mean solar day*?

3. What is the common unit of time? How is it related to the period of the earth's rotation?

4. Give a brief description of some mechanism in common use for measuring time.

5. What is the difference between *uniform* and *variable* velocities? How are uniform linear velocities measured?

6. Explain how the average velocity of a body moving with a variable velocity is estimated.

7. A line is drawn upon the floor of a railway carriage from door to door. When the carriage is at rest a ball is dropped from the roof and falls upon this line. What difference would be observed :—

(*a*) If the train is moving when the ball is dropped?

(*b*) If the train starts when the ball is half way down?

(*c*) If the ball is dropped when the train is in motion, but the train stops suddenly when it is half way down?

8. Define acceleration and give an example of a body moving with an accelerated velocity.

9. How is uniform acceleration measured? Explain the difference between a positive and negative acceleration, giving an example of each.

10. What is the system of angular measurement? Draw as nearly as you can, by estimation, angles of 30°, 45°, 60°, 90°.

11. Explain the Parallelogram of Velocities. Describe an experiment which would enable you to demonstrate it to a class.

12. A man walks backwards and forwards on the deck of a steamer along a line parallel to the direction in which the steamer is moving. If the man walks at the rate of 3·5 miles an hour, and the steamer goes through the water at the rate of 8·4 miles an hour, what is the velocity of the man with reference to the water (1) when he is walking towards the bow of the boat, and (2) when he is walking towards the stern?

13. How is the unit of time, the second, defined? Describe how you would fit up an apparatus to beat seconds.

CHAPTER VI.

INERTIA AND FORCE.

Inertia.

EXPERIMENTAL WORK.

53. *To show that a mass at rest tends to remain so.*—Suspend a heavy mass, not less than 28 lbs, from a cord. Tie a piece of cotton or thread to the mass, and then attempt to move the mass by pulling the thread sharply to one side. The thread will break and the mass will hardly be moved. The mass can, however, easily be pulled to one side if the pulling force is gradually applied.

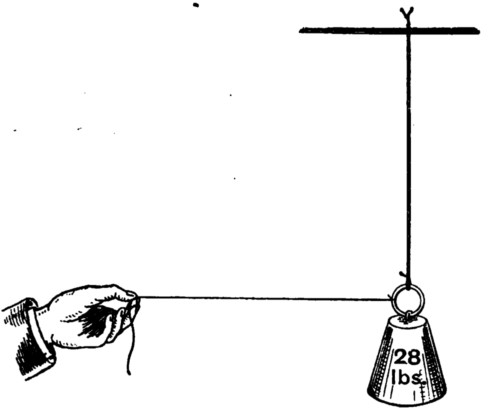


FIG. 65.—Experiment to illustrate the tendency of a body to preserve its state of rest or motion (inertia).

54. *A moving mass requires force to stop it.*—Swing the heavy mass used

in the preceding exercise to and fro by means of a thread attached to it. While it is swinging away from your hand, stop your hand suddenly. The thread will break and the mass will proceed on its swing.

Newton's First Law of Motion.—Every body will continue in its state of rest or of uniform motion in a straight line, except in so far as it is compelled by impressed force to change that state.

This statement is called a *law* of motion, and it will be well to make clear at once that a natural law is only an expression of what has been found to always be the rule; it is merely setting down the result of experience; and the idea of the word in its legal sense must be carefully excluded from the mind. Indeed in nearly every case, it is better to substitute, at all events in one's mind, the word *rule*. It is only a statement that certain things always seemed to take place; it tells us nothing about why they do so; nor is the idea of compulsion included at all, for oftentimes so-called "laws" have been formulated which have turned out to be wrong expressions of the order of nature, and evidently there could be no sort of compulsion about what was wrong, and was seen afterwards to be contrary to the general rule.

This law, which Newton first stated as being always followed by bodies in nature, means, first, that if a body is at rest, it will remain still until there is some reason for its moving—until some outside influence, which is called a *force*, acts upon it. In fact the law really supplies us with a definition of force. Nobody finds any difficulty in understanding the rule so far. But when we come to consider the second part of the law there is more difficulty in grasping it—every body will continue in a state of uniform motion in a straight line, &c. An example is afforded by a ball in moving uniformly along ice. We know that after a time the ball comes to rest and therefore that it does not continue in a state of uniform motion. But we know that it moves for a longer time on ice than it would do on a road. The ice is smoother than the road, and there seems to be a connection between the roughness or smoothness and the length of time during which the ball moves. If we imagine smoother and smoother ice, the ball will move for a longer and longer time, and we conclude that if both the ball and the ice were perfectly smooth, there is no reason why the ball should ever stop. The roughness or friction is then, in our example, the "impressed force" which causes the ball to change its state of uniform motion for one of rest. If we could have a body in a state of uniform motion outside the influence of what Newton has called "impressed forces" it would afford us an example of *perpetual motion.* But because we cannot eliminate these impressed forces we cannot have perpetual motion.

A material body is unable to change its condition of rest or of uniform motion by itself.—This inability is termed **Inertia.** We become aware of the inertia of matter most unpleasantly if we step out of a moving train on to the platform; while in the train we partook of its motion; on stepping out our feet are brought to rest suddenly, but our bodies, because of their inertia, continue to move with the velocity of the train, with the result that we fall forward on to our faces.

Momentum.

EXPERIMENTAL WORK.

55. *Collision of Equal Masses.*—Suspend two solid balls of equal mass by the side of one another, so that they just touch when at rest. Place a metre rule on edge on the table under the balls (Fig. 66). Notice the positions of the balls, and then pull each ball to an equal distance from the place where the balls rest by means of thread held in the two hands. Release the two threads at the same instant. The balls will collide, and if they are of equal mass they will rebound by equal amounts.

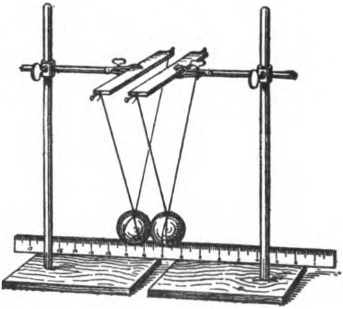


FIG. 66.—Apparatus to illustrate momentum and impact.

56. *Momentum after collision.*—Substitute a ball of much smaller mass for one of the balls in the preceding experiment. Pull the two balls away from the position of rest, so that the surfaces which touch one another are at equal distances from this position. Then release the balls simultaneously and observe the rebound. The two balls were at equal distances from their position of rest and are suspended from strings of equal length: therefore their velocities when they meet are equal. The smaller mass

has less momentum than the larger before the two meet, but the momentum after collision is the same for each mass; therefore the small mass is given a velocity of rebound as many times greater than the velocity of the large mass as this mass is greater than the smaller one.

Definition of Force.—Newton's first law enables force to be defined. *Force is that which produces, or tends to produce, motion in matter; or alters, or tends to alter, the existing motion of matter.* Here again it must be clearly understood that by defining force we do not get to know anything more about it. Nobody can tell what force is. All we can know are the effects produced by a *something* we call force.

Momentum.—The momentum of a body is the quantity of motion it has and is equal to the product of its mass and its velocity.

Expressed as an equation we have

Momentum = mass × velocity,

The unit of momentum is consequently that of a unit of mass moving with a unit of velocity, or if the unit mass be that of the imperial standard pound, **the unit of momentum is the quantity of motion in a mass of one pound moving with a velocity of one foot per second.** The meaning of momentum will be better grasped after a concrete example.

Suppose a shot fired from a cannon, the momentum generated in both the cannon and the shot will be the same; but since the mass of the cannon is immensely greater than that of the shot, it will be evident that the velocity of the shot must be correspondingly greater than that of the cannon in order that the product of the two quantities may be the same. This we know is the case, the velocity of the "kick" or "recoil" of the cannon is very much less than the velocity with which the shot is sent on its journey.

EXAMPLE.—A cannon weighing 10 tons fires a shot weighing 28 lbs. The shot leaves the gun with a velocity of 200 feet per second. With what velocity would the cannon recoil if it were free to move?

Mass of cannon = 10 tons = 22,400 lbs.
Velocity of recoil = v = ?
Mass of shot = 28 lbs.
Velocity of shot = 200 feet per second.

We know that

$$\begin{aligned}\text{Momentum of cannon} &= \text{momentum of shot}\\ \text{Or, } 22{,}400 \times v &= 28 \times 200\\ \text{Therefore } v &= 5{,}600 \div 22{,}400\\ &= \tfrac{1}{4} \text{ foot per second.}\end{aligned}$$

Force.

EXPERIMENTAL WORK.

57. *Relation between Tension and Extension.*—Clamp a thin india-rubber cord or a spiral spring with a wire by its side as in Fig. 67, and a tray suspended from the lower end. Place 10 grammes in the tray and measure the elongation produced by it—that is, measure the distance between the pin and the bottom of the wire. Place another 10 grammes in the tray and again notice the extension produced. By subtracting this reading from the former one, you can find the extra extension produced by the additional 10 grammes. In the same way, find the extension produced by 30 grammes, 40 grammes, and so on, up to 100 grammes, also determining in each case the extension for the additional 10 grammes. Record thus—

Load.	Total Extension.	Extension for 10 grams.

58. *Representation of Forces by Lines.*—Draw vertical lines to represent the extensions produced by the various loads, and also lines to represent the extension for every additional 10 grammes. As the loads represent forces, the lines will represent the extension produced by various forces. You will find that the extensions are proportional to the forces—that is, double the force double the extension, and so on. *The strength or magnitude of a force can thus be shown by the length of a line.*

59. *Parallelogram of Forces.*—The following experiments illustrate how the *directions* as well as the *magnitudes* of forces can be represented by lines.

(*a*) To the middle of a piece of elastic cord about six inches long fasten a piece of the same cord about three inches in length. From the point where the three cords meet measure off an equal distance, say two inches, and put a pin through each cord at this distance.

Fasten the pin at each end of the six inch piece of cord upon a sheet of paper lying flat upon a drawing board or table. The cord should lie in a straight line between the pins, but it must not be stretched (Fig. 68, I.). Now pull the third cord in any direction so as to stretch the

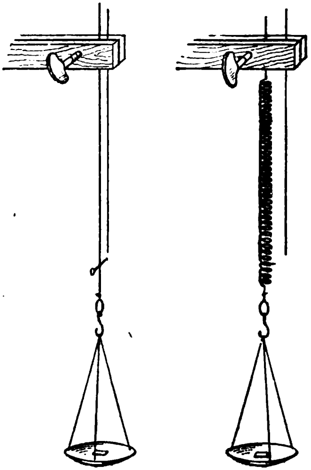


Fig. 67.—Experiment to show the extensions produced by different forces.

others as well as itself, and fasten its pin in the board while the cords are thus stretched (Fig. 68, II). Make a pin mark upon the paper at the point where the cords meet, and then pull the pins out of the paper and put them and the cords aside. Pin-holes will be marked at ABCD in Fig. 68. Mark off two inches (the distance between the pins before the cords are stretched) from each of the lines, starting from A, B, and D respectively. The lengths EC, FC, and GC thus represent the amounts by which the cords have stretched.

(*b*) Construct the parallelogram ECFH by drawing EH and FH parallel to CF and EC respectively. Draw the diagonal CH; it will be found to have the same length and be in the same line as CG. Assuming that the extensions are proportional to the forces (and they practically are so in this case), the two sides EC, CF of the parallelogram represent two of the forces, both in magnitude and direction, and the third force, which is equivalent to the other two taken together, is represented on the same scale by the diagonal of the parallelogram.

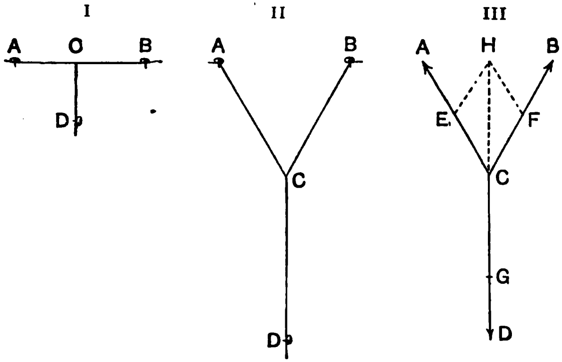


Fig. 68.—A three-way elastic cord may be used to illustrate the principle of the parallelogram of forces.

(*c*) Repeat the experiment with the cords stretched by different amounts and in different directions.

Construct a parallelogram similar to ECFH for each case.

When the cords are arranged in any position they represent three forces acting upon the particle C. Since C is at rest, the force represented by CG produces the same effect as the two forces represented by CE, CF taken together. If, therefore, a force equal in magnitude to CG, and acting in the direction CH, is substituted for CE, CF, the particle still remains at rest. The diagonal CH represents such a force both in magnitude and direction. A single force which can be substituted for two separate forces in this way is termed a *resultant* force.

The following experiments also illustrate the principle of the parallelogram of forces.

(*d*) Round two pulleys A and B, pivoted at the top corners of a board (Fig. 69), pass a fine thread to which two unequal masses are attached. To some convenient place on the thread hang a third mass from a thread as shown. Let the masses come to rest. It will be found that a parallelogram may be constructed, the sides and diagonal of which are proportional to the masses used.

(*e*) Attach a scale of inches to the edge of a black-board. Obtain two pieces of thin india-rubber cord twenty inches long, and fasten small loops of string to the two ends. Pin one of these loops to the board so that the upper end of the india-rubber cord coincides with the zero of the scale. Attach the upper end of the other india-rubber cord to any convenient point on the board. Bring the two lower ends together and hook on to them a weight (say of 100 grams). Measure off twenty inches from the upper end of each cord. The excess of length in each cord will be proportional to the tension of that cord. Complete the parallelogram with chalk, and show that the diagonal is *vertical* and is equal to the extension of the cord when it hangs vertically by the side of the scale with the weight attached.

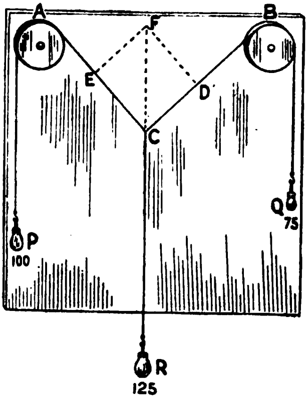


FIG. 69.—Experiment to illustrate the parallelogram of forces.

Parallelogram of Forces.—A body can only move in one direction at any given moment; but yet it can be under the influence of, or be acted upon by, any number of forces. The question arises—How can the direction be determined in which a body, under the influence of several forces at the same moment, will move, if free to move?

Or, the question may be regarded in another way. How can we substitute a single force (called the **Resultant**, which will produce the same effect), for all the separate forces acting together upon a body at the same moment?

The simple experiments you have performed supply the answer to these questions. The rule to which the experiments have led you may be stated thus:—**If two forces acting at a point be represented in magnitude and direction by the adjacent sides of a parallelogram, the resultant of these two forces will be represented in magnitude and direction by that diagonal of the parallelogram which passes through this point.**

A line may be drawn to represent graphically a force, its length being made proportional to the force, and its direction showing the direction of the force. Forces can thus be represented, both in magnitude and direction, by lines. Let O represent a material body acted upon by two forces, represented both in magnitude and direction by the lines OB, OA. To find the **resultant** of these two forces, both as regards its amount and direction, we complete the parallelogram OBRA and join OR, which will be the resultant required.

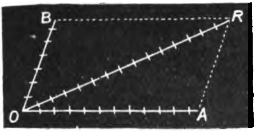


FIG. 70.—The Parallelogram of Forces.

Calculation of Resultant.—When the two forces of which the resultant is required act at right angles to one another, the calculation is a simple application of a proposition in the first book of Euclid (I. 47). In these circumstances the triangle ORA is right-angled, and Euclid proves that $(OA)^2+(AR)^2=(OR)^2$, and consequently $(OA)^2+(OB)^2=(OR)^2$, from which when OA and OB are known we can calculate OR.

When the directions of the two forces OB and OA are inclined to each other at an angle which is not a right angle, the calculation involves an elementary knowledge of trigonometry. This can be obviated, however, by the simple expedient of what is called the graphical method. This consists in drawing two lines inclined at the angle at which the directions of the forces are inclined, and making them of such length that they contain as many units of length as the force does units of force. The parallelogram is then completed by drawing AR and BA parallel respectively to OB and OA and joining the diagonal OR, the direction of which will be that of the resultant, and its length will be as many units as there are units of force in the resultant force.

Resolution of Forces.—A single force can be replaced by other forces which will together produce the same effect. Such a substitution is called *resolving* the force or a *resolution* of the force. The parts into which it is resolved are spoken of as **components**. When this has been done it is clear that we have made the original force become the resultant of certain other forces which have replaced it. Referring back to what has been said about the parallelogram of forces, it will be seen that any single force can have any two components in any directions we like; for by trying, the student will be able to make any straight line become the diagonal of any number of different parallelograms. The most convenient components into which a force can be resolved are those the directions of which are at right angles to each other. In this method of resolution, neither component has any part in the other.

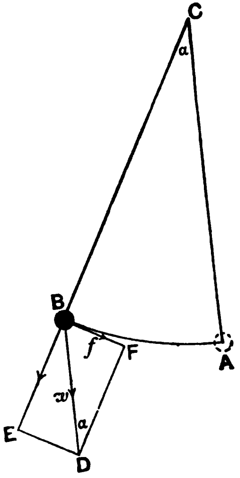


FIG. 71.—Resolution of a Force.

An interesting example of the resolution of a force into two components at right angles is afforded by a pendulum. Consider a pendulum at any point in its swing, as shown in Fig. 71. The pendulum-bob is pulled downwards in consequence of gravity, that is, the force of attraction between it and the earth, and this vertical force is represented by the line BD. The force can, however, be resolved into two forces, one (*f*) due to the inertia of B, or the tendency to continue in the direction BF, and the other represented by BE which has no part in moving the pendulum, and merely causes tension in the string BC.

A familiar example of the action of three forces in equilibrium is afforded by a boy flying a kite (Fig. 72). The tension in the string and the weight of the kite act downwards, and the wind or the air pressure against the face of the kite, gives rise to a force acting upwards. The force of the wind blowing against the face may be resolved into two forces, one acting along the kite and the other at right angles to it, tending to raise the kite. For the kite to remain at rest, the upward force due to wind or air pressure must be equal to the resultant AC of the two forces AD, AB due to the tension in the string and the kite's weight. If it is greater the kite rises, and if less the kite falls.

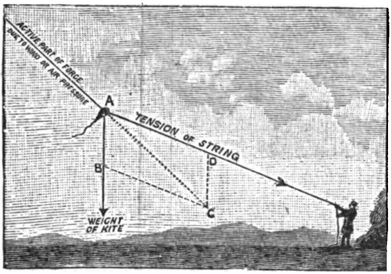


FIG. 72.—When a kite is at rest in the air, the resultant of the forces due to the tension of the string and the kite's weight is equal to the resolved part of the air pressure acting at right angles to the kite.

Angular Velocity.

EXPERIMENTAL WORK.

60. *Uniform Angular Velocity.*—(*a*) As an example of uniform angular velocity, consider the movements of the hands of a clock or watch. The ends of the second, minute hand, and hour hand move through certain distances upon the dial in each second. These distances differ from one another, but in each case equal distances are passed over every second, so that the point of each hand has a uniform angular velocity.

(*b*) Tie a ball to one end of a piece of string; hold the other end of the string in your hand, and swing the ball so that it moves around your hand in a circle. In this case, the tension of the string converts the would-be rectilinear motion of the ball into circular motion.

(*c*) Attach equal short threads to the outer edge of a circular card with a hole in the centre. Fasten light pith balls to the free ends of the threads. Slip the card over the upper part of a top while spinning, and observe the behaviour of the balls. The disc A shown in Fig. 73 may be used on a whirling table instead of on a top.

(*d*) Procure a circular hoop of thin steel, and support it upon an axis attached to a whirling table, as shown in Fig. 73. Set it spinning by turning the handle of the whirling table. Notice that the hoop assumes a more flattened form. The flattening is increased as the rate of spinning is made greater.

(*e*) Add a few drops of oil to a liquid in which they just float, as in Expt. 13 (*b*). By means of a glass rod set the liquid spinning, and notice that the drop, which was at first perfectly globular, takes the same flattened form when it is made to rotate.

(*f*) Fasten a knitting needle with wax to the lowest point of a watch glass. Moisten the glass with soap solution. Slip the needle into a vertical hole in the central peg of a top when it is spinning at a moderate rate. Blow a soap bubble on the watch glass and draw attention to the fact that it is flattened.

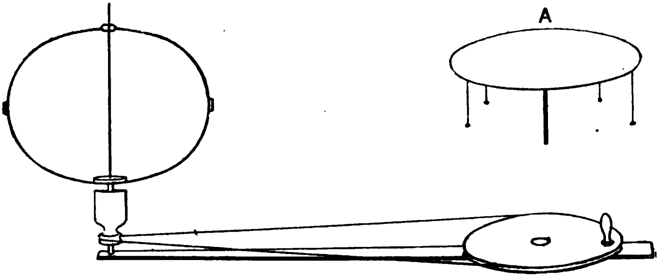


FIG. 73.—Apparatus to show the flattening produced by spinning a flexible Steel Hoop. A, cardboard disc with thread and pith balls for use in the place of the flexible hoop.

Conversion of Rectilinear into Circular Motion.—It has already been explained (p. 86) that any object, once set in motion, moves in a straight line unless the action of external force prevents it from doing so. If, therefore, a body is moving in a curve, this is because it is being continually pulled out of its rectilinear path by some force.

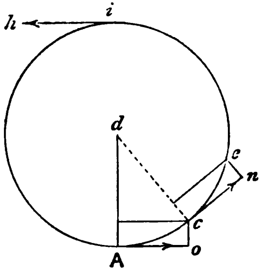


FIG. 74.—Application of the principle of the parallelogram of forces to explain Motion in a Circle.

Let A*d* (Fig. 74) represent the string used in Expt. 60 (*b*), the ball being at A. You will understand from what has been said about the resultants of forces that, if there is a force constantly pulling in the direction of the central point *d*, as well as the tendency to move in a straight line, the ball will not arrive at O after the lapse of, say, a second, but at *c*, having travelled along the curved path A*c*. The short line O*c* thus represents the pull of the string, or of the central force, at *d*. The same kind of action may be considered always to go on when an object moves in a curve; in other words, any small piece of the curve represents the resultant of two forces—one acting in the direction of a fixed point, and the other being the moving force or inertia which tends to make the object keep in a straight line. It can be shown that, in all cases when an object moves around a central point in the manner described, the pull towards the centre, whether it is represented by the tension of a string or by an attraction of some kind—is equal to the mass of the moving body multiplied by the square of the velocity, and divided by the distance from the centre to the object.

An example of motion in a curve around a centre of force, and also of the parallelogram of forces, is afforded by the moon, which moves around the earth in nearly a circular path on account of their attraction for one another. If this attraction of gravitation did not exist, the moon would leave us altogether, just as surely as the ball whose motion is represented in Fig. 74 would fly off in the direction *ih* if the string which forced it to move in a circular path were cut when the point *i* was reached.

How Rotation has affected the Shape of the Earth. —A globular body flattened towards two points, situated as far away as possible from one another, is called an *oblate-spheroid*. These points of flattening are called the *poles*, and the line joining the poles is known as the *axis*.

The experiments you have performed enable you to account for the shape of the earth. If we could be sure that the earth was spinning, and that the material of which it is made was at any time sufficiently fluid to be moulded like the drop in Expt. 60 (*e*), we should clearly be able to say that its shape was the natural result of such rotation. There can be no doubt that the earth is so spinning. We are equally sure, also, that our planet was once in a fluid state. As the student will learn more fully in other studies, many of the rocks of which the earth is built provide indisputable proof of a previous liquid condition. Moreover, the materials emitted from volcanoes during eruptions are given out as liquids. When we have studied what is known of the sun's nature we can judge by analogy what was probably the original state of the earth. These and other reasons leave no room for doubt that the earth has taken its present shape in obedience to the rules regulating the behaviour of spinning bodies which are free to move.

CHIEF POINTS OF CHAPTER VI.

Newton's First Law of Motion.—Every body will continue in its state of rest or of uniform motion in a straight line, except in so far as it is compelled by impressed force to change that state.

In other words, all matter possesses **Inertia.**

The **momentum** of a body is the quantity of motion it has, and is equal to the product of its mass and its velocity.

The **unit of momentum** is the quantity of motion in a mass of one pound moving with a velocity of one foot per second.

The **total momentum** of several moving masses remains unaltered by impact.

Force.—When a gradual change of momentum is either produced or tends to be produced in a body, that body is acted on by force.

Forces may be completely represented, both in magnitude and direction, by straight lines.

Parallelogram of Forces.—If two forces acting at a point be represented in magnitude and direction by the adjacent sides of a parallelogram, the resultant of these two forces will be represented in magnitude and direction by that diagonal of the parallelogram which passes through this point.

Resolution of Forces.—A single force can be replaced by other forces which will together produce the same effect. Such a substitution is called *resolving* the force, and the parts into which it is resolved are called *components.*

Angular Velocity.—If a body moves in a circle a force must act towards the centre of the circle. If the force suddenly ceases to act the body moves on in a straight line and thus departs from the centre of the circle. Hence curvilinear motion is an effect due to the inertia of the moving body and a force which pulls the body towards the centre of motion.

QUESTIONS ON CHAPTER VI.

1. Describe an experiment for demonstrating the principle of the parallelogram of forces to a class.

A nail is driven into a wall and two strings are tied to its head. When the two strings are pulled horizontally and at right angles to one another with forces equal to 6 and 8 lbs. respectively, the nail is dislodged. What force would be needed if the strings were brought together and the nail pulled straight out? Illustrate your answer with a diagram.

Ex. Sc.—I.

2. Two forces, the magnitudes of which are proportional to the numbers 3 and 4, act on a point at right angles to each other. Draw a parallelogram as nearly to scale as you can to show the direction and magnitude of the resultant, and deduce by measuring your diagram, or in any other way, the magnitude of the resultant.

3. What is meant by the parallelogram of forces? Give a diagram to illustrate your answer.

Describe an experiment by means of which the truth of the proposition may be verified.

4. Explain what is meant by angular velocity. If two precisely similar bodies travel with the same speed in two circular orbits, of which the radii are in the proportions of 3 to 4—(1) what will be the ratio of the angular velocity about the centre of the larger to that about the centre of the smaller circle; (2) which body is acted on by the greater force to retain it in its circular path?

5. Enunciate Newton's First Law of Motion. Explain what you understand by a natural law.

6. Explain what is meant by the inertia of a material body. Give as many of the results of the possession of this property by a material body as you can.

7. The horizontal and vertical components of a certain force are equal to the weights of 60 lbs. and 144 lbs. respectively. What is the magnitude of the force?

8. State the law of gravitation, and show briefly how its action and the moon's inertia cause the moon to move in a nearly circular path around the earth.

9. Account for the flattening of the earth at its poles.

10. A boy flies a kite. What forces are acting on the kite when it is at rest in the air? Draw a diagram to show the direction of each.

Explain why the string must not be tied to the lower part of the kite.

11. Four forces act at a point. The first of 10 lbs. acts due north, the second of 15 lbs. due east, the third of 20 lbs. due south, and the fourth of 25 lbs. due west. Find the magnitude and direction of the resultant.

12. Two spring balances are attached by strings to a ring which is placed round a nail driven into the table, and the balances are stretched in directions at right angles to one another till one indicates a pull of 16 lbs. and the other of 9 lbs. Draw a figure showing the direction and magnitude of a *single* force which would produce the same pressure on the nail as do the *two* forces due to the pulls of the balances.

How would you prove experimentally the correctness of your result?

13. State the "parallelogram of forces." You are provided with three small spring balances (sometimes called "dynamometers"), a blackboard, chalk, string, &c.; how can you verify the proposition?

CHAPTER VII

THE LEVER AND PARALLEL FORCES

The Lever

EXPERIMENTAL WORK.

61. *Balancing Equal Masses on a Lever.*—Make or obtain a lever consisting of a strip of light wood graduated in centimetres and having a thin ring screwed into one edge, above the central point, and a hook screwed into each end (Fig. 75). Hang the lever from a nail in the middle ring. If it does not exactly balance, plane off a little from the end which sinks or slightly unscrew the hook at the end which rises above the horizontal, until the lever does set itself horizontally.

Hang two pill-boxes or small linen bags by their strings from the lever, one on each side of the fulcrum or pivot, at equal distances from it. Into one of the bags place a mass of say 50 grams, and find how many grams you must place into the other bag in order to restore equilibrium.

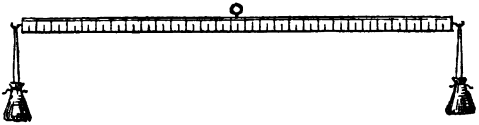


FIG. 75.—A simple Lever.

Repeat the experiment with the bags at a different distance.

You will always find that equilibrium is obtained when equal masses are at equal distances from the turning point or fulcrum.

62. *Principle of Moments.*—Place some pieces of lead in each of four linen bags, and adjust by means of shot or bits of lead until their masses are respectively 50 grams, 100 grams, 200 grams, and 300 grams. Place the 100 gram bag about 12 cm. from the fulcrum of the lever and balance it with a 50 gram bag on the other side. Record the distance from the fulcrum in each case. Repeat the experiment by balancing 50 grams against 100 grams, 50 grams against 200 grams, 100 grams against 300 grams, and other combinations.

Record your observations in columns as below:

LEFT SIDE OF LEVER.		Load × Distance.	RIGHT SIDE OF LEVER.		Load × Distance.
Load.	Distance from Fulcrum.		Load.	Distance from Fulcrum.	

Compare the numbers in columns 3 and 6, and state in words the law or rule indicated by the results.

The experiment shows you that there is a definite proportion between the masses on the two sides of a lever, and their distances from the fulcrum. The proportion is:

$$\begin{matrix}\text{Left}\\ \text{load}\end{matrix} : \begin{matrix}\text{Right}\\ \text{load}\end{matrix} :: \begin{matrix}\text{Right}\\ \text{distance}\end{matrix} : \begin{matrix}\text{Left}\\ \text{distance}\end{matrix}$$

Or, expressed in another way, the loads are inversely proportional to their distances from the fulcrum.

The turning effect of any force acting upon a lever, as each mass did in the experiment, is termed the *moment* of the force. The comparisons of colums 3 and 6 has shown you that the *moment* or turning effect is measured by the product load and distance from the fulcrum.

(*b*) Hang two bags on the same side of the lever at different distances and one bag on the other side. Move the single bag until equilibrium is obtained. Do this several times with the bags in different positions and compare the sum of the moments of the forces acting on one side with the moment of the force on the other side.

(*c*) Hang a small book or a bag with shot or nails in it on one side of the fulcrum and the 100 gram bag from the other. Move this bag along the lever until equilibrium is obtained. Then remembering that

$$\text{Load}_1 \times \begin{matrix}\text{Distance}_1\\ \text{from fulcrum}\end{matrix} = \text{Load}_2 \times \begin{matrix}\text{Distance}_2\\ \text{from fulcrum}\end{matrix}$$

calculate the mass of the book or bag of nails. Repeat the experiment using the 200 gram bag.

In the preceding experiment the fulcrum has been between the forces acting upon the lever. The effort exerted and the load may, however, both act on one side of the fulcrum.

63. *Load between Effort and Fulcrum.*—Suspend the lever from its middle hook as before. Attach a spring balance near one end and suspend a load from some point between the balance and the fulcrum. The principle of moments applies to this case as to the others and you will find that

$$\begin{matrix}\text{Reading of}\\ \text{balance}\end{matrix} \times \begin{matrix}\text{Distance of balance}\\ \text{from fulcrum}\end{matrix} = \text{Load} \times \begin{matrix}\text{Distance from}\\ \text{fulcrum.}\end{matrix}$$

The forces acting in this experiment are the same as those called into play when a man lifts the handles of a wheelbarrow having a load in it.

64 *Effort between Load and Fulcrum.*—Suspend a load from one end of the lever supported upon the central hook. Attach a spring balance to the lever between the load and the fulcrum and hold the lever horizontal by means of it. Keeping the balance between the load and the fulcrum, show that whatever the relative distances of the two from the fulcrum the principle of moments holds good when the lath is kept horizontal. This class of lever is similar, as regards the distribution of forces, to sugar-tongs and ordinary fire-tongs.

65. *The Principle of Work applied to Levers.*—Hang the lever upon a nail on a wall, and when it is horizontal draw a line on the wall along the upper edge. Hang the 100 gram bag from the hook at one end of the lever, and the 300 gram bag on the other side. Move this bag until it counterpoises the other. Now turn the lever so that the point from which the 300 gram bag is suspended moves through 4 or 5 cm. from *B* to *b* (you can measure this distance by means of compasses). Also measure the distance *Cc* through which the end of the long arm moves. Compare the small with the larger value in each measurement, thus:

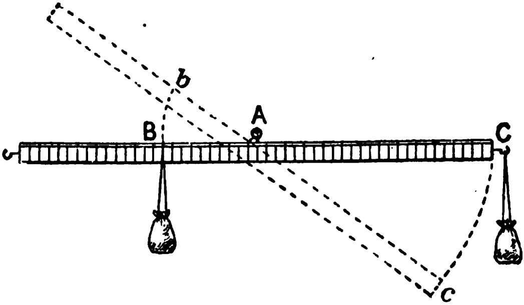


FIG. 76.—Principle of work illustrated by a lever.

$\frac{\text{Length of Long Arm}}{\text{Length of Short Arm}}$	$\frac{\text{Length of Long Arc, } Cc}{\text{Length of Short Arc, } Bb}$	$\frac{\text{Large Load.}}{\text{Small Load.}}$

Repeat the experiment with different masses.

Machines.—A machine is a contrivance by means of which a given force is made to resist or overcome another force acting in a contrary direction.

What are termed "the mechanical powers" are really simple machines which can be used to overcome resistance. We have now to consider the mechanical principles underlying the action of such simple machines as the lever, the pulley, the inclined plane, and the screw.

The Lever.—A lever is a rigid bar which can be freely turned about a fixed point. The *fulcrum* of a lever is the fixed point about which the lever can be turned. The force exerted when using a lever is often described as the *Power* and the body lifted or resistance overcome as the *Weight*. These words are convenient but they are not correctly used in connection with levers, as their true meanings are confused by so doing. It is better to substitute the word *effort* for power and *resistance* or *load* for weight.

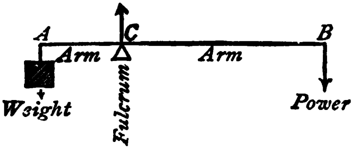


FIG. 77.—Names used in connection with Levers.

It should be borne in mind, that, so far as mechanical principles are concerned, there is no difference between the power and the weight; both represent forces, and as such they must be considered in the action of levers. The perpendicular distances from the fulcrum to the lines of actions of forces acting upon a lever, are known as the *arms* of the lever. In Fig. 77 the distance *AC* is the arm at one end of which the "Weight" acts, and *BC* is the arm at one end of which the "Power" acts.

Classes of Levers.—For convenience, levers are divided into three orders or classes, according to the relative positions of the fulcrum, and the forces in action. The classes are as follows:—

Class I. Fulcrum between resistance and effort. Examples: see-saw, a pump-handle, a balance, a spade used in digging (Fig. 78).

Class II. Resistance between effort and fulcrum. Examples: nutcrackers, a wheelbarrow, and others shown in Fig. 79.

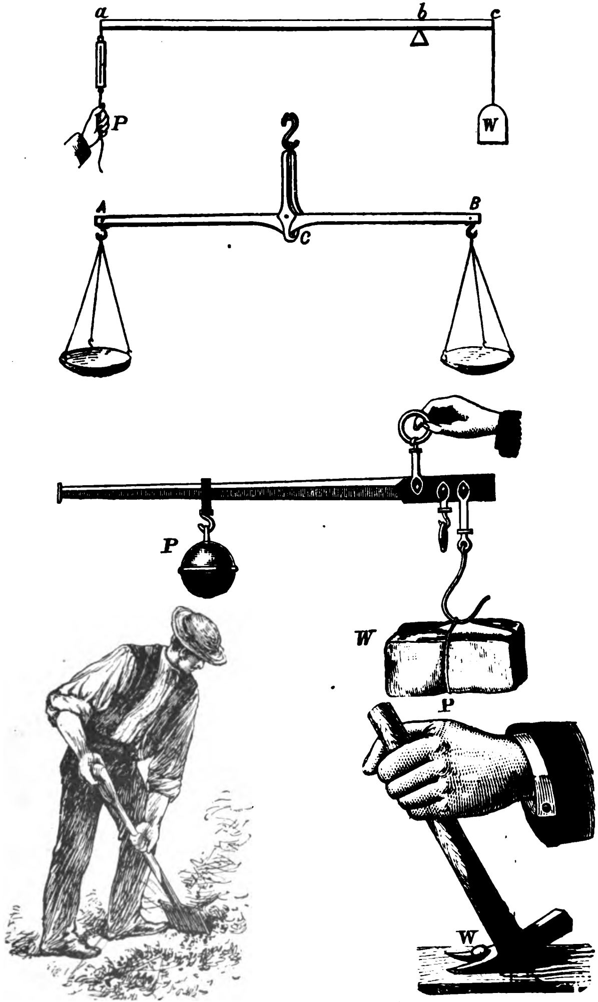


FIG. 78.—Levers of the first order.

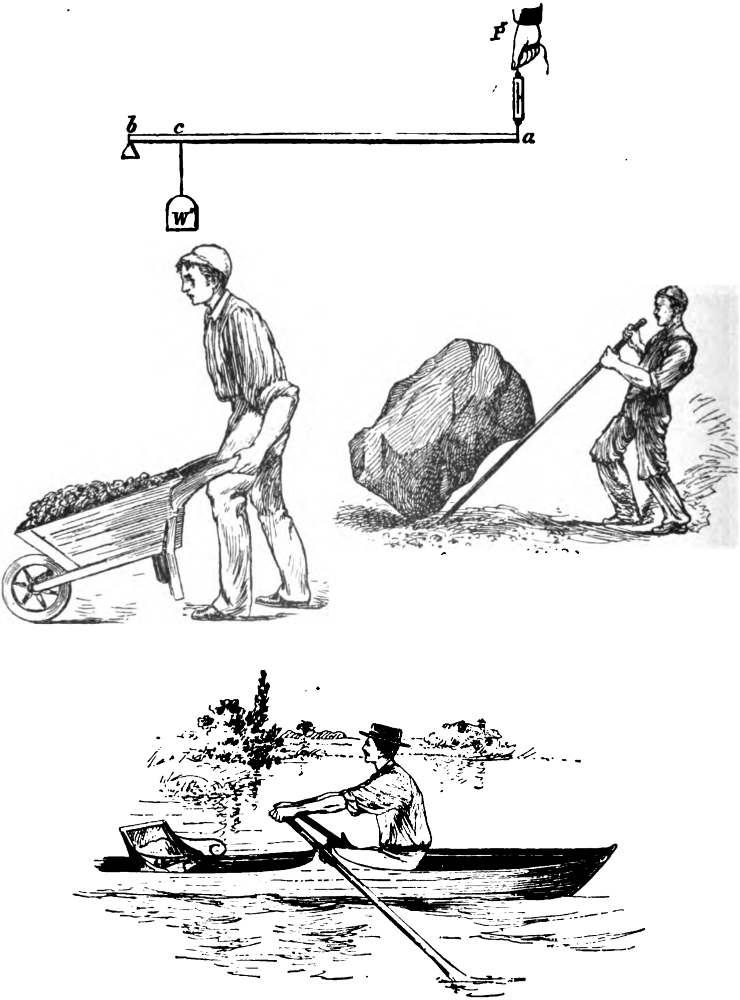


FIG. 79.—Levers of the second order.

Class III. Effort between fulcrum and resistance. Examples: sugar-tongs, ordinary fire-tongs, the pedal of a grindstone (Fig. 80).

These classes are of no real consequence, for the principle underlying the action of all levers is the same.

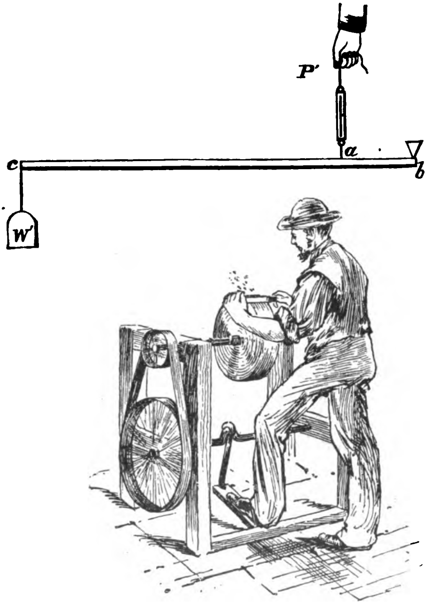


FIG. 80.—Levers of the third order.

Principle of the Lever.—Your experiments have proved, that when a lever is in equilibrium

Mass on one side × Distance from fulcrum = Mass on other side × Distance from fulcrum.

This principle of moments applies to all levers, so that all you have to consider, when thinking over the action of a lever of any kind, are the forces working in one direction and their distance from the fulcrum compared with the forces or resistances which oppose them and the distance of these from the fulcrum.

Moments.—In order to clearly understand what is meant by the moment of a force consider the experiments demonstrating the principle of the balance (p. 47) and those just performed. Let Fig. 81 represent the condition of things when the lath is in equilibrium with the pans carrying unequal masses at different distances from the fulcrum. When there is equilibrium we may say that the turning effects of the forces, about the point of suspension, acting on the lath at the points where the pans are supported are equal. The turning effect of a force is termed the *moment* of the force.

Refer to the diagram (Fig. 81), where F is the point of support of the lath, and M_1 is a larger mass at a distance AF in equilibrium with a smaller mass M_2, at a greater distance FB.

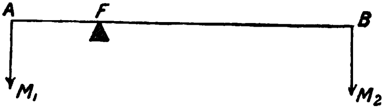


FIG. 81.—To illustrate moments of Forces.

The force acting at A is, as you know, the weight of the mass M_1, acting vertically downwards; and the force at B is the weight of the mass M_2 acting in the same direction. The moment of the force acting vertically downwards at A is the product of the force equal to the weight of M_1 and the distance AF, which as the diagram shows is measured at right angles to the direction in which the force acts. Similarly the moment of the force equal to the weight of the mass M_2, about the point F, is equal to the product of this force and the vertical distance BF.

This is a rule of universal application for taking moments which will have to be used several times later on, and must be very carefully learnt :—

The moment of a force about any point is the product obtained by multiplying this force by the perpendicular distance between the point and the line of action of the force.

But it must always be remembered that the force and the perpendicular distance between its line of action and the point about which moments are taken must be expressed in suitable units.

The Principle of Work.—It will be seen more fully later that work is measured by the product of a force into the distance through which a body is moved in the direction of the force. Now, in every case where such simple machines as the lever, pulley, inclined plane and screw are concerned, the work done by one set of forces is equal to that done by the other.

Experiment 65 has shown that this is true for a lever; for the values obtained in each of the three columns there tabulated are practically the same, thus proving that when a force or effort exerted upon one arm of a lever moves a load or overcomes resistance at the other end, the distance through which the effort is exerted bears the same proportion to the distance through which the resistance is overcome that the resistance itself bears to the effort. In other words, what is gained in force is lost in distance, so that in each case the product of force and distance is the same whether the lengths of the lever arms or the arcs through which the ends of the lever moves are taken as the distances.

From the principle of work it follows that if a man, by exerting a force of 10 lbs. on one end of a crowbar, moves 100 lbs. at the other end, he has to exert his effort through 10 inches in order to move the mass one inch. In other words, what is gained in effort has to be made up by distance moved.

Parallel Forces.

EXPERIMENTAL WORK.

The forces which you have dealt with in the experiments with levers were parallel forces, so that the following experiments only extend the principles you have already studied.

66. *Example of Parallel Forces.*—Place the ends of a stiff lath or rod of uniform thickness upon two letter balances, or support the rod by hanging each end from a spring balance. Notice the load borne by each balance; then weigh the rod, and so determine the proportion of the load supported at each end.

67. *Upward and Downward Forces in Equilibrium.*—(*a*) Using the same arrangement as before, notice the reading shown by each balance when the lath is supported. Then place a mass anywhere upon the lath

and again observe the reading of each balance (Fig. 82). Repeat the experiment with the mass in different positions on the lath, and record the results in columns as shown below :—

Mass supported by A.	Mass supported by B.	Total readings A + B.	Mass of lath plus load.

If columns 3 and 4 are compared after performing an experiment of this kind they will be found to be practically the same, thus again showing that when the lath is in equilibrium the sum of the upward forces is equal to the sum of the downward forces.

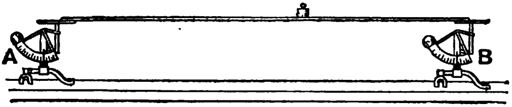


FIG. 82.—To illustrate Experiment 67.

(*b*) A similar experiment can be performed by suspending a light lath horizontally from two spring balances, and hanging a mass from any point between the balances. In this case the total reading of the balances will be equal to the weight of the load and the lath taken together.

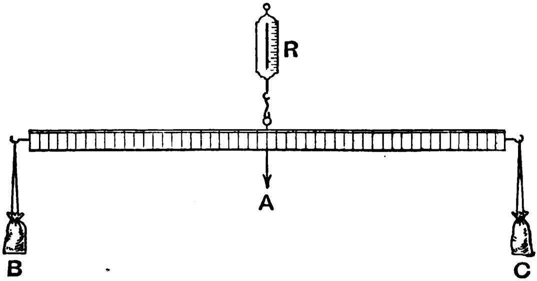


FIG. 83.—The reading of the spring balance is equal to the total weight of the lath and the loads.

68. *Resultant of Parallel Forces.*—(*a*) Suspend a light lath from a spring balance by the ring above its centre (Fig. 83). Notice the reading of

the balance. Hang two *equal masses* in bags from the ends of the lath, and again observe the reading of the spring balance. Repeat the experiment with *unequal masses* placed in bags arranged on the lath so as to counterpoise one another.

Mass of lath A.	Mass, B	Mass, C.	Total $A + B + C$.	Reading of spring balance, R.

By comparing columns 4 and 5 it will be seen that the three downward forces A, B, and C, acting upon the lath, are kept in equilibrium by one upward force R.

(*b*) Hang the two masses B and C in one bag from the middle of the lath suspended from the spring balance. Notice that the reading of the balance is the same as when the two masses are hung from the ends of the lath.

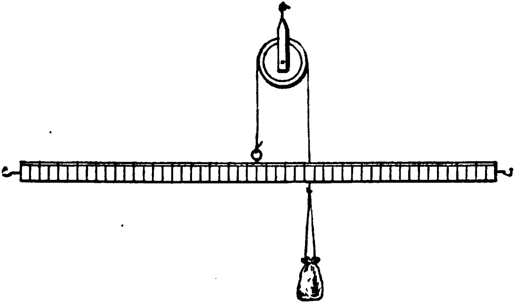


FIG. 84.—Lever suspended for experiment in parallel forces.

When a single force can be substituted in this way for two or more separate forces without affecting the equilibrium of the body acted upon it is said to be a *resultant*, and the separate forces are termed *components*.

69. *Conditions of Equilibrium of Parallel Forces.*—To further study accurately the conditions of equilibrium of parallel forces, a method is required which does away with the necessity of considering the mass of the lever. This is obtained as follows:

(*a*) Suspend the lath by a string which passes over a pulley and has attached to the other end a mass equal to the mass of the lath (Fig. 84). The rod can then move as if it had no mass.

Upward forces can be applied to it by spring balances, or masses attached to strings passing over pulleys and downward forces by hanging masses from it.

Attach a spring balance to any convenient point on the lath by passing the hook of the balance through a hole in the lever or by means of thread.

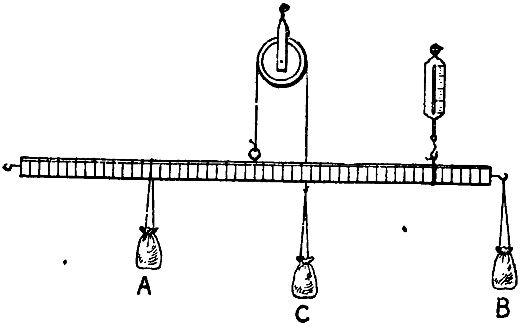


FIG. 85.—Parallel forces in equilibrium.

Suspend masses *A* and *B* from the lath so that they counterpoise one another (Fig. 85). Notice reading of spring balance and masses used.

Add an additional mass to that used to counterpoise the lath, and also add masses to the lath to restore equilibrium.

Mass, *A*.	Mass, *B*.	Total downward forces, weights of $A+B$.	Weight of additional Mass, *C* =upward force.	Downward force −upward force.	Reading of a spring balance. (Resultant).

A comparison of columns 5 and 6 will show you that the pull on the balance is equal to the difference of the forces acting downwards and upwards respectively. The reading of the balance shows, in fact, the value of the resultant of all the forces acting upon the lath.

(*b*) Remove the masses, except the one counterpoising the lath. Select a mass equal to the previous resultant reading of the spring balance. Hang it from the lath, and move it about until the reading of the spring balance is the same as before.

You can thus prove that the direction of the resultant force passes through the fulcrum formed by the supporting hook of the spring balance.

70. *Equilibrium of Three Parallel Forces.*—Using the same arrangement as before, suspend masses from the lath and move the spring balance along the lath until they counterpoise one another. Repeat the experiment with different loads, and observe in each case (*a*) the reading of the spring balance, (*b*) the distance of each mass from the point at which the spring balance is attached to the rod, (*c*) the total distance between the masses. It will be found that one mass multiplied by its distance from the point of action of the resultant is equal to the product of the other mass by the other's distance from the resultant.

Or, as has already been proved by the simple lever—

$$\left.\begin{array}{c}\text{Sum of moments on one}\\ \text{side of fulcrum}\end{array}\right\}=\left\{\begin{array}{c}\text{Sum of moments on other}\\ \text{side of fulcrum.}\end{array}\right.$$

Parallel Forces.—We have seen that the earth exerts a downward pull upon all objects on its surface, and that in consequence of this all things fall to the ground if unsupported. It follows, therefore, that everything which is supported above the earth's surface is constantly being pulled downwards, even though it does not fall. If a beam, for instance, is supported horizontally by resting the ends upon two posts, each particle of it may be regarded as being pulled earthwards by an attractive force. The direction of the pull is everywhere towards the centre of the earth, so for any one spot on the earth's surface we may consider the attractive forces due to gravity to be parallel to one another.

When a stiff lath or rod of uniform thickness rests upon two letter balances, or is supported by hanging each end from a spring balance, the experiment represents on a small scale the case of a beam referred to before, and by using the spring balances we further see that the weight of a beam is equally divided between the two supports. In other words, we find that the two upward forces exerted by the balances are together equal to the downward force represented by the weight of the beam.

If a load be placed anywhere upon the lath, it is still found by reading the balances that when the lath is in equilibrium the sum of the upward forces is equal to the sum of the downward forces.

Principle of Parallel Forces.—We are now in a position to state definitely the principle of parallel forces demonstrated by the experiments you have performed. It may be expressed as follows :—"**The resultant of a number of parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the opposite direction.**" In other words, we may say, the resultant is equal to the *algebraic* sum of the forces.

If two *equal parallel forces* act in the same direction upon a body, the total force will be obtained (as might be expected) by adding the two individual forces together. In like manner, if two *unequal parallel forces* act in opposite directions the net effect will be found by subtracting the lesser of the two forces from the greater, and the direction of the resultant will be that of the greater force.

Resultant of Parallel Forces.—It has been shown experimentally that the resultant of a system of parallel forces is equal in *magnitude* to the algebraic sum of the forces ; the *direction* of the resultant is the same as that of the greater of the parallel forces. This is illustrated by the experiments (p. 110) in which a mass attached to the end of a string which passes over a pulley and is fixed to the centre of a lath eliminates the mass of the rod ; for while the forces due to the loads on the rod act vertically downwards, the resultant, represented by the pull of the spring balance, acts vertically upwards. The *position* which the resultant occupies with reference to the component forces is also shown by the same experiments. It is similarly exemplified by Experiment 70, where different loads are suspended from the rod and the spring balance is moved along the rod until the position of equilibrium is obtained.

A record of this kind not only shows that the magnitude of the resultant force is equal to the sum of the components, but it also proves that in each case when the rod is in equilibrium one force multiplied by its distance from the point of action of the resultant is equal to the other force multiplied by the other's distance from the resultant. Or, expressing the result as an equation we have :—

$$\begin{matrix}\text{Force on}\\ \text{one side}\end{matrix} \times \begin{matrix}\text{Distance from}\\ \text{Resultant}\end{matrix} = \begin{matrix}\text{Force on}\\ \text{other side}\end{matrix} \times \begin{matrix}\text{Distance from}\\ \text{Resultant.}\end{matrix}$$

If the component forces are equal, their distances from the resultant will also be equal ; and if they are unequal the resultant will always be nearer to the greater force. In other words, a small force is at a large distance from the resultant, and a large force is at a small distance.

Conditions for the Equilibrium of Three Parallel Forces.—The student should now be in a position to understand clearly the conditions which must prevail for three parallel forces to be in equilibrium.

Carefully consider the experiment in which a rod bearing a load is supported from two spring balances (Fig. 83).

Neglecting the mass of the rod, this experiment is a demonstration of the conditions for the equilibrium of three parallel forces. The weight will be found to be equal to the sum of the readings of the spring balances. In other words, the resultant force will be found equal to the sum of the components. Moreover the readings of the spring balances will be found to be in inverse ratio to the distances of the balances from the weight; while the weight itself will be proportional to the length of the rod between the balances. The relation is shown graphically by Fig. 86, in which the directions of the three forces are represented by the lines CW, AD, BE. The forces bear exactly the same proportion to one another as the distances AB, BC, CA. We have, therefore, as the conditions of equilibrium of three parallel forces the following expression:—

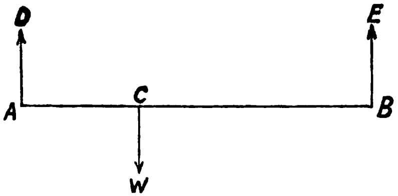


FIG. 86.—Equilibrium of parallel forces.

$$\frac{\text{Force CW}}{\text{Distance AB}} = \frac{\text{Force AD}}{\text{Distance BC}} = \frac{\text{Force BE}}{\text{Distance CA}}$$

Or, expressed in words, *each force is proportional to the distance between the other two forces.*

EXAMPLE.—A mass of 120 lbs. is suspended from a light rod (the mass of which may be neglected), the ends of which rest upon the shoulders of two men, A and B (Fig. 87). The rod is 6 feet long, and the load is 2 feet from the man A, and 4 feet from the man B. What proportion of the total mass is borne by each man?

From the above we see that

$$\text{Amount borne by A} : \text{Amount borne by B} = \text{B's distance from load} : \text{A's distance from load}$$
$$= 4 : 2 = 2 : 1.$$

So that the man A bears twice as much as the man B, that is, he bears 80 lbs. and B carries 40 lbs.

Caution.—In concluding this section on parallel forces a word of warning is necessary. Parallel forces are frequently confused with the parallelogram of forces, on account of the slight similarity between the words. It must, however, be borne in mind that in a case of the parallelogram of forces, the component forces are never parallel to one another, but inclined at an angle. The resultant also is *not* equal to the algebraic sum of the components, as it is in the case of parallel forces.

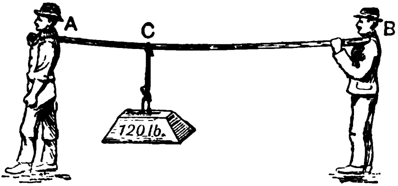


FIG. 87.—Relation of parallel forces to one another.

CHIEF POINTS OF CHAPTER VII.

A **Machine** is a contrivance by means of which a given force is made to resist or overcome another force acting in a contrary direction.

A **Lever** is a rigid bar which can be freely turned about a fixed point (the *fulcrum*). The force exerted when using a lever is called the *effort*, and the body lifted, or force overcome, the *resistance*.

Classes of Levers.—For convenience, levers are divided into three classes:—

1. Fulcrum, between resistance and *effort*. Examples:—See-saw, pump-handle, balance, crowbar.

2. Resistance between effort and fulcrum. Examples :—Nut crackers, wheelbarrow, and boat oar.

3. Effort between resistance and fulcrum. Examples :—Sugar tongs or ordinary fire-tongs.

Principle of Lever :—

$$\text{Mass on one side} \times \text{Distance from fulcrum} = \text{Mass on other side} \times \text{Distance from fulcrum}$$

Moments.—The turning effect of a force is termed the *moment of a force.* The moment of a force about any point is the product obtained by multiplying this force by the perpendicular distance between the point and the line of action of the force.

Parallel Forces.—The resultant of a number of parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the opposite direction.

Moreover, in case of parallel forces, not only is the magnitude of the resultant force equal to the sum of the components, but when there is equilibrium—one force multiplied by its distance from the point of action of the resultant is equal to the other force multiplied by the other's distance from the resultant.

QUESTIONS ON CHAPTER VII.

1. Describe the principle of the action of a simple lever.

A stiff wooden rod, six feet long, and so light that its weight may be neglected, lies upon a table with one end projecting four feet over the edge. Upon the end of the rod lying on the table a weight of 8 lbs. is placed. What weight must be placed upon the other end so as just to tip the rod?

2. A uniform rod is pivoted at its middle point, and a weight of 20 grams is attached at a point 25 centimetres from the fulcrum. To what point on the rod must a weight of 15 grams be attached in order that the rod may balance in a horizontal position?

3. Give a simple illustration of each of two different kinds of lever.

4. Describe an experiment to prove that the resultant of a number of parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the opposite direction.

5. State the conditions for the equilibrium of three parallel forces. Describe an experiment which shows these conditions.

6. Apply the principle of moments to explain the conditions or equilibrium for parallel forces. Give an example.

7. State briefly why it is that a lever may be used so that the force exerted by one end of it is greater than the force exerted upon the other end.

8. What is meant by the "principle of work"? Apply the principle to the case of a lever.

9. What is a lever?

What is the "fulcrum" of a lever?

Name four or five levers in common use, and say where the fulcrum of each may be.

10. Two forces, P and Q, act upon a body. If P acted alone it would, in two seconds, produce in the body a velocity of 10 feet per second, while if Q acted alone it would in three seconds produce in the body a velocity of 18 feet per second. What velocities will P and Q produce in one second when acting together if the directions in which they tend to move the body are—(1) inclined; (2) directly opposed?

11. What is meant by the resultant of two forces?

Describe an experiment to prove that the resultant of two parallel forces is equal to the algebraical sum of the forces.

CHAPTER VIII

PRINCIPLES OF THE PULLEY, THE INCLINED PLANE, AND THE SCREW

The Simple Pulley

EXPERIMENTAL WORK.

71. *Single Fixed Pulley.*—Hang a pulley from a stand or nail, and over the wheel or sheaf pass a fine flexible cord having a loop tied at each end. Connect a light tray or bag with each end of the cord. Put a mass in one of the trays and then gradually place bits of lead or small nails in the other until the first tray moves (Fig. 88). When this happens, take each of the trays and find the mass of each with its contents. Repeat the experiment with different masses, and record your results in parallel columns.

The two trays with their contents will be found to have very nearly the same mass, but not exactly, for in order to move the tray *W*, the mass *P* must be a little greater than that of *W*, as the friction of the pulley upon its axle has to be overcome.

72. *Tension in String Supporting Movable Pulley.*—(*a*) Place a weight in one of the trays previously used, and suspend the tray and a pulley together from a spring balance. Record the reading of the balance. Now arrange the pulley and balance as shown in Fig. 89, and again record the reading.

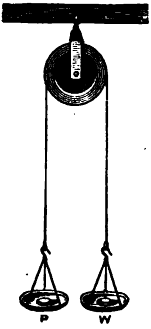


FIG. 88.—A single fixed pulley.

Load, W.	Reading of Spring Balance, *P*.	Ratio $\frac{P}{W}$

It will be noticed that P is only $\frac{1}{2}$ W (roughly) in every case; in other words, the tension in a cord supporting a movable pulley having a mass hung from it is equal to one half the total mass supported.

(*b*) Hang the tray with weights in it, together with two pulleys, from a spring balance, as before, and observe the reading. Then arrange the pulleys in connection with the spring balance as shown in Fig. 90, and again observe the reading. Tabulate your observations.

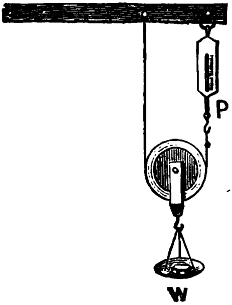


FIG. 89.—A single movable pulley.

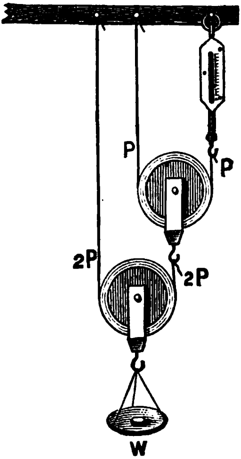


FIG. 90.—Two movable pulleys.

Load (pulleys and mass W).	Reading of Spring Balance, P.	Ratio $\frac{P}{W}$

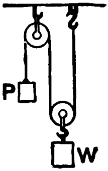


FIG. 91.—One fixed and one movable pulley.

In this case, that is, with two movable pulleys, it will be noticed that the force required to support the pulleys and load is less in proportion than when one pulley was used.

Another way to determine the advantage of using movable pulleys is to pass the free end of the cord over a fixed pulley, as in the following experiment, instead of connecting it with a spring balance.

73. *Mechanical Advantage.*—Arrange one fixed and one movable pulley as in Fig. 91. Place various masses in succession in the tray W, suspended from the movable

pulley, and add lead or shot to the tray P until W begins to move. Then disconnect the pulleys and find the mass of P and its contents, and the total mass of W and the movable pulley. Tabulate your observations thus:

Total Mass lifted (W + pulley).	Moving Force, P.	$\frac{\text{Total Mass}}{\text{Moving Force.}}$

74. *Principle of Work applied to Pulleys.*—When the load and moving force are in equilibrium in the preceding experiment, mark the height of the bottom of each tray from the table. Then move the tray P through a certain distance and observe how much the tray W is moved. It will be found that:

$$P \times \text{distance moved} = W \times \text{distance moved.}$$

The Pulley.—A pulley is a wheel having a grooved rim, and capable of rotating about an axis through its centre. The frame which holds the pulley is called the block.

Most satisfactory experimental results are obtained by using pulleys made of aluminium, which can now be obtained at a small cost. In pulleys of this sort the errors due to friction are almost eliminated. Your experiments have shown you that although a movable pulley, that is one which can move up and down, reduces the effort which has to be exerted to support a given mass, a fixed pulley is of no advantage in that respect. The number of times that the resistance overcome or mass moved exceeds the effort exerted or moving force is known as the *mechanical advantage* of a machine.

The way in which pulleys enable resistance to be advantageously overcome is demonstrated by the experiments you have performed to learn the uses of single fixed pulleys and single movable pulleys.

Use of a Single Fixed Pulley.—With a single *fixed* pulley, no mechanical advantage is obtained. All that the pulley does is *to change the direction of the pull*; if one of the loads, for instance, is pulled down, the other rises. The pulley thus acts in the same way as a lever balanced at its centre: the distance from the centre to the circumference, in other words, the radius of the pulley, being regarded as one arm of the lever. A pulley having a radius of three inches has therefore an equivalent lever-arm three times as great as one with a radius of one inch.

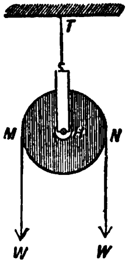


FIG. 92.—Parallel forces acting on a pulley.

A pulley supported as in Fig. 92, may be considered as an example of the action of parallel forces. The two forces W+(W+the weight of the pulley), acting downwards, are kept in equilibrium by the single force T acting upwards. If a single mass, the weight of which is equal to W+W+pulley, were hung from the cord, it would produce the same tension as the three forces, that is it would be their resultant.

Use of a Single Movable Pulley.—The fixed pulley, as has been already seen, is of no advantage in reducing the force required to raise a mass; the advantage gained is derived from the use of a movable pulley. For instance, in the case of the experiments represented in Figs. 89, 91, one half of the mass W is supported by the part of the string hooked to the beam, and the other half is supported by the part of the string which goes around the fixed pulley to the mass marked P, or to the spring balance. There are several different combinations of pulleys, but the principle exemplified by the foregoing experiments, namely, that every movable pulley reduces by one-half the effort required to support or raise the mass below it is utilised in them all.

The Principle of Work applied to Pulleys.—With pulleys, as with levers, there is neither loss nor gain of work. If, in any combination of pulleys, a force of 10 lbs. balances a force of 120 lbs.—the mechanical advantage, resistance ÷ effort, thus being 12—the effort will have to be exerted through twelve feet in order to move the resistance through one foot. For it is an invariable rule that

$$\text{Effort} \times \begin{array}{c}\text{the distance through}\\ \text{which it acts}\end{array} = \text{Resistance} \times \text{distance moved.}$$

The mechanical advantage of any system of pulleys can therefore be determined (1) by finding the relation between the load moved and the force exerted, or (2) by comparing the distance through which the force is exerted with that through which the force moves.

The Inclined Plane.

EXPERIMENTAL WORK.

75. *Principle of the Inclined Plane.*—Arrange a hinged board with a weight attached by elastic to the free end. Show that the tension is less when the weight rests on the board than when it is suspended freely.

76. *Relation between Effort and Load, when the Effort is exerted parallel to the plane.*—(*a*) Obtain a large pill box or small canister, and run a knitting needle through it from end to end to form an axle (Fig. 93). Fit a wire handle upon the axle, and attach to it a spring balance or an elastic cord.

Place some shot or sand in the roller thus constructed. Pull the roller along the hinged board used, with the board horizontal, and notice how much the cord or spring balance is stretched. Now tilt the board slightly and pull the roller up it as in Fig. 94, taking care that the direction in which you pull is parallel to the slope of the board. Observe the amount by which the cord stretches as you pull up the roller. Then hold the cord vertically and find what mass will stretch it by the same amount. The weight of this represents the force used. Weigh the roller and so obtain the mass moved. Afterwards measure the length AC and the height AB, and find the relation between them as below—

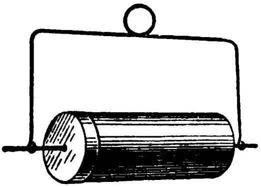


FIG. 93.—Roller for inclined plane.

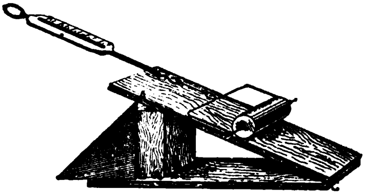


FIG. 94.—Force acting parallel to an inclined plane.

$$\frac{\text{Load moved}}{\text{Force exerted}} = \frac{\cdot\ \cdot\ \cdot\ \cdot}{\cdot\ \cdot\ \cdot\ \cdot} =$$

$$\frac{\text{Length of plane}}{\text{Height of plane}} = \frac{\cdot\ \cdot\ \cdot\ \cdot}{\cdot\ \cdot\ \cdot\ \cdot} =$$

Are the two results approximately the same? If so, you may conclude that the mechanical advantage of an inclined plane, when the force exerted acts parallel to the plane, is equal to the length of the plane divided by the height.

In measuring an inclined plane, any vertical line such as AB (Fig. 95) can be taken as the height, provided that the two other sides of the triangle which it forms are taken as the length and base of the plane.

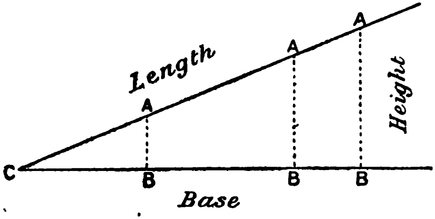


FIG. 95.—Height, length and base of an inclined plane.

(*b*) Repeat the experiment with the inclined plane, that is the board, tilted at different angles, and with different amounts of shot in the roller. Record in columns as below—

Load.	Force.	Height of Plane.	Length of Plane.	$\frac{\text{Load.}}{\text{Force.}}$	$\frac{\text{Length.}}{\text{Height.}}$

(*c*) Your experiments have shown you that, in the case of the inclined plane, when the power acts parallel to the plane

$$\text{Mechanical advantage} = \frac{\text{length of plane}}{\text{height}}.$$

Fix the board at any convenient height, and calculate the mechanical advantage by finding the ratio of the height to the length of the plane. Afterwards test whether the calculated result agrees with the result obtained by finding practically the ratio of the force exerted to the mass moved in the case of the inclination chosen.

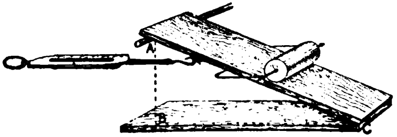


FIG. 96.—Force acting horizontally on an inclined plane.

77. *Relation between Effort and Load, when the Effort acts horizontally.*—(*a*) Arrange the roller as shown in Fig. 96. Keeping the india-rubber cord horizontal, pull the roller up the inclined plane. Observe the stretch of the india-rubber, and find what mass will produce the same amount; or if you are using a spring balance, observe the reading under these conditions. Then weigh the roller and the wire handle. Measure the lengths of BC and AC.

$$\text{Mechanical advantage} = \frac{\text{Load moved}}{\text{Force exerted}} = \frac{\dots}{\dots} =$$

$$\frac{\text{Base of plane}}{\text{Height of plane}} = \frac{\dots}{\dots} =$$

Do your results bear out the statement that when a load is being pulled up an inclined plane by a force which acts horizontally, the ratio which the force bears to the load, in other words, the mechanical advantage, is equal to the base of the plane divided by the height?

(*b*) Repeat the preceding experiment with the board tilted at different angles. Record your results as below—

Mass used.	Force exerted.	Height of Plane.	Base of Plane.	$\frac{\text{Load.}}{\text{Force.}}$	$\frac{\text{Base.}}{\text{Height.}}$

This experiment and the preceding one will enable you to understand the action of a *Wedge* (Fig. 102), which may be considered as two inclined planes, base to base. In this case the plane is pushed forward by a power acting parallel to the common base. The principle is therefore just the same as when an object is pulled up an inclined plane by a power acting parallel to the base, but the direction of action is reversed.

78. *Friction.*—(*a*) Fix a small staple, such as is used to fasten wire netting, into one end of a rectangular block of wood. Place the block upon a smooth table, and connect an india-rubber cord or spring balance with it by means of a bent pin. Hold the balance horizontal and slowly pull it until the block moves. Notice the amount by which the india-

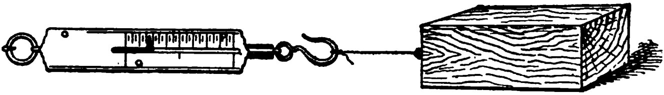


FIG. 97.—Measurement of friction.

rubber is stretched, or the reading of the balance, when this happens. Repeat the experiment several times upon the same part of the table, and notice that the force required to move the block is roughly the same in each case.

(*b*) Repeat the preceding exercise with the block upon a slate or a sheet of plate glass instead of upon the table.

The surfaces upon which the block was placed in the two preceding exercises were comparatively smooth, so the *friction* between the block and the surfaces was not very great. Try the experiment with the block upon a sheet of sand-paper.

(*c*). Exercises 78 (*a*) and (*b*) prove that the amount of friction varies with different surfaces in contact with one another. To test whether the **size** of the surface of contact has any effect upon the amount, repeat the experiments with the block upon one of its side faces, taking care that the direction of the grain is the same as before. It will be found that the same pull or force is required to move the block when the surface in contact is small as when it is large.

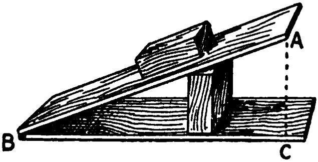


FIG. 98.—Limiting angle of friction.

79. *Limiting Angle of Friction.*—Another method of studying effects of friction is by inclining the board or table upon which the friction block rests. Obtain a smooth board about 18 in. long and 4 in. wide. Place the rectangular block already used upon the board, and raise the upper end of the board until the block begins to slide. Measure the perpendicular height to which the board can be raised before the motion commences. Repeat the experiment with the block on the side face used before.

The Inclined Plane.—A plane in mechanics is a rigid flat surface, and an inclined plane is one that makes an angle with the horizon.

The reason for the decrease of tension in an elastic cord attached to a mass resting on a hinged board, compared with the tension when the mass hangs freely, will be best understood by applying the principle of the parallelogram of forces to the inclined plane. Suppose an object O (Fig. 99) is kept in

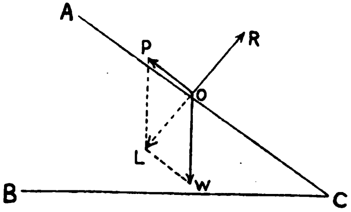


FIG. 99.—Parallelogram of forces applied to an inclined plane.

position upon a smooth inclined plane by a force acting up the plane, as in Expt. 76 (*a*). The object is acted upon by three forces, namely, W, due to its weight, acting vertically downwards, P, the force exerted up the plane, R the reaction of the plane. The weight acting downwards is thus kept in equilibrium by the two forces R and P acting upwards. The last-named force represents the effort exerted, and being one of two it is evidently less than the weight whenever the object rests upon the plane.

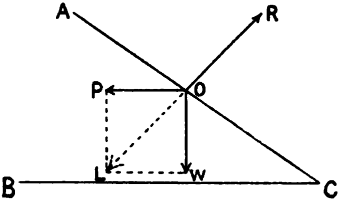


FIG. 100.—Parallelogram of forces applied to an inclined plane.

Let OP and OW be drawn of lengths proportional to the force exerted up the plane, and the weight ot the object, O. Complete the parallelogram PLWO, and draw the diagonal OL. This parallelogram represents graphically in magnitude and direction the forces in equilibrium when a body of definite weight is kept in position upon a smooth inclined plane, by a force acting up the plane. If the sustaining force acts horizontally, the parallelogram shown in Fig. 100 represents the forces concerned, OP representing the effort exerted, OW the weight, and OL the pressure on the plane.

Friction on an Inclined Plane.—In the cases hitherto considered it has been assumed that there is no friction between the object and the inclined plane, so that a sustaining force has

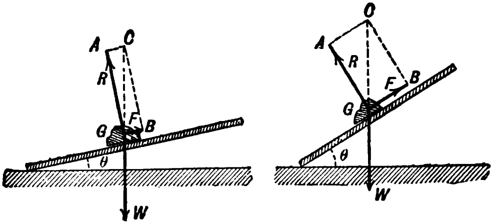


FIG. 101.—Forces in action when an object rests upon an inclined surface.

to be used as soon as the plane is inclined. When there is friction between the surfaces of contact of the object and the plane, the object may remain at rest without any effort being exerted. Let G in Fig. 101 represent a stone or other object at rest upon a plane inclined by different amounts. As the object is at rest the action of the plane must be equal and opposite to the weight of the object. If the weight is represented by the vertical line GW the action of the plane is shown by a line, GC, of the same length. This action can be considered to be the consequence or resultant of two separate forces—one, F, due to friction, and acting up the plane, and another, R, due to pressure, acting perpendicular to the plane. The parallelogram AGBC thus represents the forces in action in each case. When the inclination is small friction is small, and therefore GB is small in comparison with GA, which represents the pressure. As the inclination is increased, friction, F, increases, and R, pressure, upon the plane decreases.

Advantage of the Inclined Plane.— In experiments with the hinged board upon which a load was kept at rest by means of a force acting along the length of the plane, or horizontally, it was found that the effort, or force used, was less than the load, and that the proportion which one bears to the other differs with different inclinations of the plane. There is a definite relation between this proportion and the slope of the plane on which the load moves. When the force is exerted parallel to the plane, this proportion is as follows :—

$$\begin{matrix}\text{Mass} \\ \text{moved}\end{matrix} : \begin{matrix}\text{Force} \\ \text{exerted}\end{matrix} :: \begin{matrix}\text{Length of} \\ \text{plane}\end{matrix} : \begin{matrix}\text{Height of} \\ \text{plane.}\end{matrix}$$

This rule can also be deduced from the principle of work. If the roller starts from C Fig. 94 and moves to A, it is lifted through the vertical height AB. For this to take place, the force will have to be exerted through a distance equal to the length of the plane AC. Therefore

$$\frac{\text{Load}}{\text{Force}} = \frac{\text{Distance through which the force is exerted}}{\text{Vertical distance through which mass is lifted}}$$

$$\text{Or, Load} \times \text{height of plane} = \text{Force} \times \text{length of plane.}$$

When the effort acts horizontally, the ratio which it bears to the weight is in the proportion which the *base* of the plane BC bears to the height AB.

A **wedge** can be considered to be two inclined planes base to base, this double plane being pushed forward by a force exerted parallel to the direction of the base. Fig. 102.

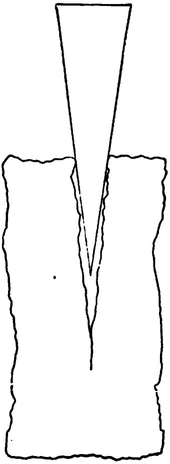


FIG. 102.—A wedge.

The Screw.

EXPERIMENTAL WORK.

80. *Screw and Nut.*—Obtain a large screw or bolt and a nut into which it fits (Fig. 103). Scratch a line along the tops of the screw thread from one end of the screw to the other in the direction of the axis.

Place your rule along the screw and see how many of the spaces between successive threads are equal to the length of an inch. You can thus find the distance between two successive threads. Another way is to measure the length between, say, 11 threads, and divide this by 10 to find the distance from one thread to the next. Record this distance in your note-book.

Put the bolt upon the screw and turn it until it reaches one of the marks scratched upon the thread. Make a line upon the bolt at the point where the scratched thread touches it. Turn the screw, and notice that one complete turn brings another mark to the side of the line upon the bolt.

You thus see that one complete turn advances the screw by an amount equal to the distance between two successive threads. You know what this distance is, and can therefore write down the distance through which the screw advances for any number of turns.

Find (i) by calculation, using the value you have found for the distance between successive threads, (ii) by direct measurement, the amount of advance of the screw with reference to the nut when it is given 7, 8½, 10, 11½, and 14 turns.

To understand the principle utilised in the preceding exercise, a model screw thread should be constructed as follows.

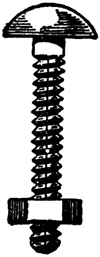


FIG. 103.—Screw and nut.

81. *Construction of a Model Screw Thread.*—Cut out of paper a right-angled triangle such as ABC (Fig. 104) and wind it round a lead pencil. The slant side of the triangle forms a spiral upon the pencil, similar in appearance to the thread of a screw. If the inclination of our triangle is small, the threads appear close together, and if it is large they occur farther

apart. Mark where the end C of the paper touches the base of the triangle and draw a line DE, perpendicular to the base, from this point to the slant side. The small triangle CDE thus formed is similar to the large one, and it represents one turn of the screw-thread.

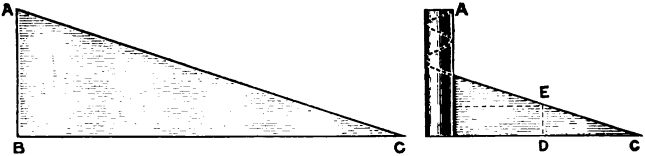


FIG. 104.—Formation of a screw thread by the slope slide of an inclined plane.

Principle of the Screw.—Comparing the screw-construction now with an inclined plane, it will be seen that

height of inclined plane represents distance between threads,
base of ,, ,, ,, circumference of screw.

The angle of inclination of the inclined plane is represented by the angle ECD (Fig. 104), and this determines the *pitch* of the screw.

In considering the use of a screw, the resistance to be overcome can be regarded as a load upon an inclined plane. With a screw such as is shown in Fig. 105 the force acts in a direction parallel to the base of the plane. Under this condition

Load : Force :: Base of Plane : Height of Plane

Or, expressing the proportion in the terms which apply to screws :—

Resistance : Effort :: Circumference of Screw : Distance between successive threads.

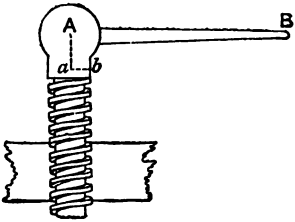


FIG 105.—A screw turned by a lever.

When the force is applied at B, leverage is gained in the proportion of AB to *ab*, and so further mechanical advantage is obtained on this account. But, in order to advance the screw by a distance equal to that between two successive threads, the end of the handle B has to be turned through a complete circumference. This fact can be used to deduce the mechanical advantage of a screw from the principle of work. We get, in fact,

$$\frac{\text{Resistance}}{\text{Effort}} = \frac{\text{Circumference of circle described by power-arm.}}{\text{Distance between successive threads.}}$$

CHIEF POINTS OF CHAPTER VIII.

The **Pulley** is a wheel having a grooved rim, and capable of rotating about an axis through its centre. The frame which holds the pulley is called the block.

Mechanical Advantage.—The number of times that the resistance overcome exceeds the effort exerted is known as the mechanical advantage of a machine.

A Single Fixed Pulley gives no mechanical advantage. All that it does is to change the direction of the pull.

A Single Movable Pulley gives a mechanical advantage. Every movable pulley reduces by one-half the effort required to raise a given load.

Principle of Work applied to Pulleys:—

$$\text{Effort} \times \begin{matrix}\text{The distance through}\\ \text{which it acts}\end{matrix} = \text{Resistance} \times \text{Distance moved.}$$

The Inclined Plane is a rigid flat surface which makes an angle with the horizon.

Advantage of the Inclined Plane when the Force is exerted parallel to the Plane:—

$$\text{Mass moved} : \text{Force exerted} :: \begin{matrix}\text{Length of}\\ \text{Plane}\end{matrix} : \begin{matrix}\text{Height of}\\ \text{Plane}\end{matrix}$$

or

$$\frac{\text{Mass}}{\text{Force}} = \frac{\text{Distance through which force is exerted}}{\text{Vertical distance through which mass is lifted}}.$$

Therefore,

$$\text{Force} \times \text{distance exerted} = \text{mass} \times \text{vertical distance moved.}$$

A **Wedge** can be considered as two inclined planes base to base. This double plane is pushed forward by a force exerted parallel to the direction of the base.

Principle of the Screw.—The distance between successive threads represents the height of an inclined plane; the circumference of the screw represents the base of an inclined plane. Moreover,

$$\text{Load} : \text{Force} :: \text{Base of Plane} : \text{Height of Plane.}$$

$$\text{Resistance} : \text{Effort} :: \begin{matrix}\text{Circumference}\\ \text{of Screw}\end{matrix} : \begin{matrix}\text{Distance between}\\ \text{successive threads}\end{matrix}$$

$$\therefore \frac{\text{Resistance}}{\text{Effort}} = \frac{\text{Circumference of arc described by power arm}}{\text{Distance between successive threads}}.$$

QUESTIONS ON CHAPTER VIII.

1. State the principle of the action of a simple pulley.

How would you show that the strain or tension in a cord supporting a pulley is equal to half the weight hanging from the pulley?

2. One end of a piece of india-rubber cord is pinned to a drawing-board longer than the cord; to the other end a weight is attached. The drawing-board is slightly inclined by lifting the edge to which the india-rubber is pinned. What effect has this upon the india-rubber?

Is the effect increased or decreased when the inclination is made greater? Show, by means of a diagram, the direction of the forces which act upon the weight when it rests upon the inclined drawing-board.

3. Describe the action of a single movable pulley in decreasing the force which has to be exerted to support a given weight.

4. Show, by means of the parallelogram of forces, the action of an inclined plane when the effort is exerted parallel to the plane.

5. Describe the relations between the inclined plane and the screw.

6. A pulley is hung from a beam and a cord is passed round the groove. A mass of one pound is hung from one end of the cord. What mass must be put at the other end of the cord to produce equilibrium?

7. Explain by reference to an inclined plane what you understand by the "mechanical advantage" of a machine.

8. Give in a few words the principle of the screw. On what does the ratio of the resistance overcome to the effort exerted depend?

9. What do you understand by the "Limiting Angle of Friction"? Describe an experiment to explain your meaning.

10. Explain how a weight, a pulley, and a chain can be arranged so as to make a door shut when it is let go. Draw a diagram. What forces has the weight to overcome as it shuts the door?

11. A penny lies at rest on a sloping desk. What forces are acting on it? Draw a diagram showing clearly the direction of each.

CHAPTER IX

CENTRE OF GRAVITY

Determination of Centres of Gravity

EXPERIMENTAL WORK.

82. *Centre of Gravity of Uniform Rod.*—Procure an uncut pencil. Tie a piece of thread round the pencil and adjust the thread in such a position that the pencil is suspended horizontally from it. Measure the distance of the thread from each extremity of the pencil. The pencil may be regarded as a straight line, and the observations will show that the *centre of gravity* is in the middle of it.

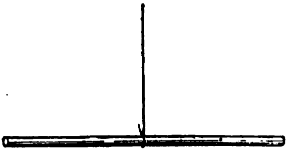


FIG. 106.—Centre of gravity of uniform rod.

83. *Centres of Parallel Forces.*—Arrange a rod as shown in Fig. 85, but instead of only two masses A and B there shown, hang several at different places along the rod. Determine by trial where the spring balance must be so that the rod is balanced. The position of attachment of the balance to the rod marks the centre of gravity of the system.

84. *Experimental Methods of Determining Centre of Gravity.*—(*a*) Procure a disc of sheet cardboard and find by trial the point on which it may be balanced, that is, the centre of gravity of the disc. Make a hole in the card near the edge, and take a plumb line consisting of a thread with a piece of lead tied at one end and a hook of thin wire at the other. Hang the disc from the hook, and then suspend both as shown in Fig. 107, so that

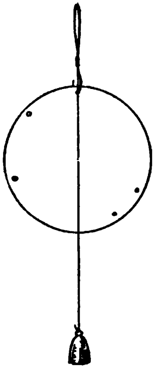


FIG. 107.—A determination of centre of gravity.

the disc and lead are both suspended and the thread passes over the point of suspension. Observe it also passes through the centre of gravity. Do this for various holes in the edge of the disc and see that in all cases the *vertical line through the point of suspension passes through the centre of gravity.*

(*b*) Another way to find the centre of gravity of plane figures such as have been described is to tie a string around the edge at each hole. Then hang the plate by one of the strings to a support such as one of the rings of a retort stand. Allow it to come to rest and using a straight edge, draw a chalk mark across the plate in the same straight line with the string as shown by the dotted line in the figure. Now attach the same plate by one of the other threads exactly as before and again make a mark in continuation of the string. The two chalk marks intersect at a point marked G, Fig. 108. Untie and do the same with another string, the third line passes through the intersection of the first two. Obtain a similar point for each of the other plates. Also determine in the same way a similar point for irregular plates of wood, zinc, or cardboard.

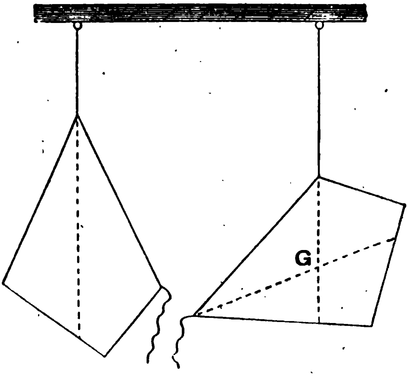


FIG. 108.—A determination of centre of gravity.

85. *Centre of Gravity of a Parallelogram.*—Determine experimentally as in Expt. 84, the centre of gravity of a plate in the form of a parallelogram. Mark the point with a pencil; then turn over the plate and draw the two diagonals upon the opposite side. Make a pin-hole where the diagonals intersect. The point where the diagonals intersect will be found to be practically the same as the centre of gravity.

86. *Centre of Gravity of a Triangular Plate.*—Repeat the preceding experiment with a triangle cut out of cardboard. After finding the centre of gravity prick a pin-hole through the cardboard, then turn over

the triangle and draw a line from each angle through the pin-hole to the opposite edge. Now, taking each edge in turn as the base of the triangle, determine (i) the lengths of the two parts into which each base is divided by the lines drawn, (ii) the proportion which the distance of the hole from each base bears to the length of the line from that base to the opposite angle.

87. *Centre of Gravity of a Quadrilateral.*—Cut a four-sided figure out of cardboard, and draw a line connecting two of the opposite angles. Find by bisecting this line and taking one-third the distance from the middle to the opposite angle, the centre of gravity of each of the triangles into which the figure is divided. Connect the two points found. Then draw the other diagonal of the quadrilateral, repeat the measures, and connect the centres of gravity as before. Make a hole where this short line cuts the other, and show, by passing a piece of knotted thread through it, and so suspending the cardboard, that the point determined in this way is the centre of gravity of the whole figure.

88. *Centre of Gravity of an Irregular Plane Figure.*—Select a piece of cardboard of any shape, and find its centre of gravity. Test, as before, whether the cardboard will set horizontally when suspended from the point found.

89. *Centres of Gravity of Skeleton Solids.*—(*a*) Procure a skeleton cube or a tetrahedron, and suspend it as in the preceding experiments. Mark the verticals through the point of suspension by light wires attached by wax, and thus find the position of the centre of gravity. The centre of gravity will not be on any point of the skeleton solid used.

(*b*) Find the centre of gravity of an open wickerwork basket, such as a waste-paper basket. To do this, suspend the basket, and hang a plumb-line from the point of suspension. Tie a piece of thread across the basket in the direction of the plumb-line; then suspend the basket from two other points, and notice where the plumb-line crosses the thread in each case. The point of intersection, which need not be actually on the framework itself, is the centre of gravity.

Centre of Gravity.—Consider a large number of weights, some heavier than others, suspended from a horizontal rod arranged as in Fig. 85. A certain position can be found at which the spring balance has to be attached in order to keep the rod in equilibrium. When the rod is hung from this point the tendency to turn in one direction is counteracted by the tendency to turn in the other, so the rod remains horizontal. The weights may be regarded as parallel forces, and the pull of the spring balance as equal to their resultant. Now consider a stone, or any other object, suspended by a string. Every particle of the stone is being pulled downwards by the force of gravity, as indicated in Fig. 109. The resultant of these parallel forces is represented by the line GF, and the centre of the forces by the point G. The point G, through which the resultant (GF) of the parallel forces due to the weights of the individual particles of the stone passes, is known as the **centre of gravity**. For the stone to be in equilibrium, the string must be attached to a point in the line GF, or GF produced.

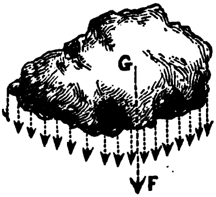


FIG. 109.—Parallel forces due to gravity.

Every material object has a centre of gravity, and the position of this point for a particular object is the same so long as the object retains the same form.

Experimental Methods of Determining Centre of Gravity.—The centre of gravity of such geometrical figures as circles, squares, and parallelograms is really the centre of the figures, and can therefore be determined geometrically. In the case of unsymmetrical figures, however, the centre of gravity cannot be so easily found by geometry, and is best determined by experiment.

The experimental method adopted for determining the centre of gravity of any material body depends upon the considerations set forth in the preceding paragraph. The body, the centre of gravity of which is required, is allowed to hang quite freely, either by means of a cord or on a smooth peg, and when it has come to rest a vertical line through the point of support is traced by means of a straight edge. If a string is employed, this vertical line will be a continuation of the string, and is at once drawn by the help of a ruler. If the body which is being experimented with is hung from a smooth nail, by means of a hole bored in it, the vertical line must be drawn with the help of a plumb line. The point of support is now shifted and the operation repeated. Since the centre of gravity of the plate is in both straight lines it must be located at their intersection.

Plates of all Shapes Balance about their Centres of Gravity.—After the centre of gravity of a sheet of metal, or other material, has been determined by hanging it from a support in the manner described in Experiment 84, it will be found that if it be so arranged that a pointed upright is immediately under the centre of gravity, the plate will be supported in a horizontal position. This affords a convenient means of checking the correctness of the experiment performed.

Geometrical Determination of Centres of Gravity.—It has been sufficiently explained that the centre of gravity of straight lines, circles, squares, and other regular figures is at their geometrical centres. Hence, the geometrical constructions for determining these central points also locate the position of their centres of gravity.

The centre of gravity of a parallelogram is at the intersection of its diagonals.

The centre of gravity of a triangle is determined by bisecting any two sides and joining the middle points so obtained to the opposite angles. The intersection of the lines so drawn gives the centre of gravity. The centre of gravity is found, by measuring, to be one-third the whole length of the line drawn from the middle point of the side, to the opposite angle away from the side bisected.

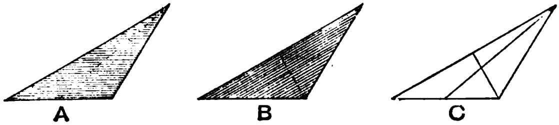


FIG. 110.—Geometrical illustration of centre of gravity of a triangular plate.

We may, in fact, consider a triangular plate as made up of a number of narrow strips of material which decrease in length from the base to the apex. The centre of gravity of each strip is the middle of the strip ; hence the line drawn from the apex to the middle of the base passes through each centre of gravity. By taking another side as base, a similar line can be drawn from the middle to the opposite angle. These lines intersect at one-third the distance up the line so drawn, measured from the base, and the point of intersection is the centre of gravity of the triangular plate (Fig. 110).

To find the centre of gravity of a quadrilateral by construction, the plan is to divide it into two triangles by drawing a diagonal. By the method just described find the centre of gravity of each triangle and join the points so obtained. The centre of gravity of the quadrilateral lies on this line. Repeat the process drawing the other diagonal, join the centres of gravity of the second pair of triangles, the centre of gravity of the quadrilateral lies on this line. Hence it is located at the point of intersection of this line and the first obtained in the same way.

Centres of Gravity of other Bodies.—The method of drawing lines across the surface of a thin plate is not suitable in the case of bodies such as blocks or skeleton solids having three dimensions. Experiments (89*a*) and (89*b*) explain two methods which can be usefully employed in other cases. The ingenuity of the student will provide other equally suitable plans for particular cases.

Equilibrium.

EXPERIMENTAL WORK.

90. *Relation of Centre of Gravity of a Plane Figure to Base of Support.*—Place upon a square-edged table or board one of the cardboard figures of which you have found the centre of gravity. Gradually slide the figure near the edge until it would just topple over; keeping it in this position draw a line along the under side of the cardboard where the edge of the table touches it. Then place the cardboard in another position and again mark where the edge of the table touches it when it would just topple over. The intersection of these lines is the centre of gravity, and it will be noticed that the cardboard would just topple over when the centre of gravity falls outside the edge of the table.

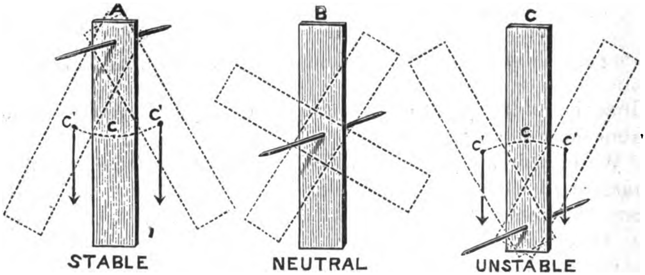


FIG. 111.—Conditions of equilibrium.

91. *Stable, Neutral, and Unstable Equilibrium.*—Procure an oblong strip of board or cardboard (Fig. 111). Bore a hole through the oblong

near one end, and one through the middle. Support the strip as at A; it is then in stable equilibrium, for the slightest turn either to right or left raises the centre of gravity. When supported as at B, the strip is in neutral equilibrium; and when supported as at C it is in unstable equilibrium.

92. *Conditions of Stability.*—See whether any of the cardboard figures used in the preceding experiments can be hung loosely from a pin with the centre of gravity above the pin. Try the experiment with the pin at different distances from the centre of gravity. In each case notice the direction of the line connecting the centre of gravity with the point of support when the figure comes to rest.

93. *Equilibrium of Objects Resting upon a Base.*—(*a*) Procure an oblong block of wood of about the same size as this book, and about three inches thick. Draw the two diagonals on one of the faces; the centre of gravity of the block will be inside the block at a point below the intersection of the diagonals. Press a pin partly into the block at the point where the diagonals intersect, and suspend from it a small plumb line made of a short piece of thread and a bit of lead (Fig. 112). Now place the block upon the board, and notice the direction of the plumb-line. Tilt the board until the block topples over. When this happens notice the direction of the plumb-line with reference to the base. It will be found by this experiment that the block topples over as soon as the plumb-line falls beyond the base.

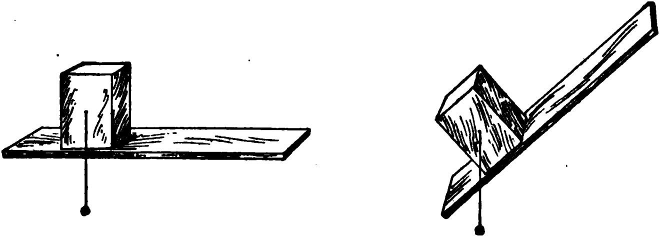


FIG. 112.—To illustrate the relation between centre of gravity and base of support.

(*b*) Repeat the preceding experiment with thick blocks of wood triangular in shape, and with cylinders and cones. In this way show that a body is only in equilibrium when the centre of gravity is vertically above some point of the supporting surface.

(*c*) Stand with your left shoulder and left foot touching a vertical wall. Now attempt to keep the right foot raised. Why can you not do so though you are able to keep the left foot raised?

(*d*) Try to balance a pointed pencil upon one of your fingers. It is not easy to do so because a slight movement throws the centre of gravity of the pencil outside

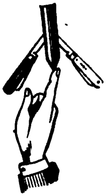


FIG. 113.—The centre of gravity is below the point of support.

the point of support. Stick two pocket knives in the pencil as shown in Fig. 113. The centre of gravity of the combination is thus brought below the point of support and the pencil can therefore be kept upright without difficulty.

Relation of Centre of Gravity to Base of Support.—A circular disc, in which it will be remembered the centre of gravity coincides with the geometrical centre, will not rest upon a table if the centre is beyond the edge of the table, but will topple over. In a similar way if any plane figure lies flat upon a table the centre of gravity of the figure must be within the edge of the table. The same conditions apply to any object resting upon a support. For an object resting upon a base to be in equilibrium, a vertical line drawn from the centre of gravity downward must fall within the base. When this vertical line falls outside the base the body topples over.

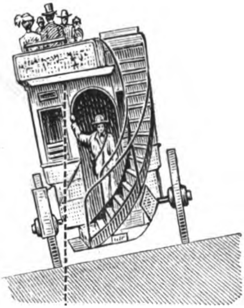


FIG. 114.—If a vertical line from the centre of gravity falls outside the base of support, an omnibus will topple over.

Consider the case of an omnibus on level ground. The centre of gravity is somewhere inside the omnibus and a vertical line drawn from it downwards would fall within a line traced around the omnibus upon the ground. But if the outside of the omnibus is filled with people and the vehicle happens to be running across a sloping road, it might topple over, for a jerk might cause so great a change of position of the centre of gravity as to make the vertical line from the centre fall outside the base of support, and in such a case an accident must happen (Fig. 114).

A man carrying a heavy load in one hand affords a familiar instance of the relation of the centre of gravity to the base of support. When he is without any load he stands upright and the centre of gravity falls within a line drawn around his feet. But when he carries a load the combined centre of gravity is not centrally placed above his feet but nearer the side carrying the load than it was before, and the man leans to the other side in order to bring the centre of gravity again above his base or support (Fig. 115).

Equilibrium.—When a body is at rest all the forces acting upon it balance one another (or, what is the same thing, any force is equal and opposite to the resultant of the remaining forces) and it is said to be in equilibrium. It is in *stable equilibrium* when any turning motion to which it is subjected raises

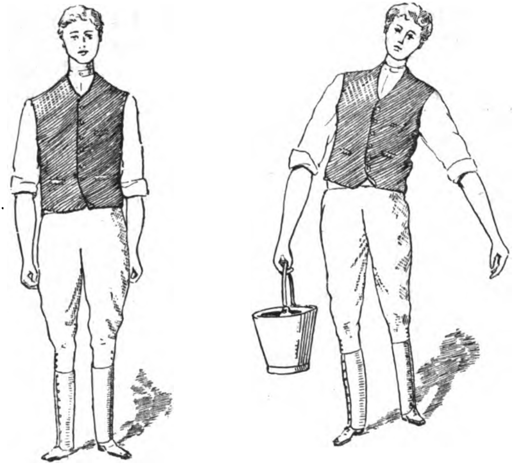


FIG. 115.—When a man is carrying a load he leans to the opposite side in order to keep his centre of gravity above and within the base of support.

the centre of gravity; in *unstable equilibrium* when a similar movement lowers the centre of gravity and in *neutral* equilibrium when the height of the centre of gravity is unaffected by such movement. Consequently, if a body in stable equilibrium is disturbed, it returns to its original position; if in unstable equilibrium, it will, if disturbed, fall away from its original position; while if the condition of equilibrium is neutral it will, in similar circumstances, stay where it is moved to.

A ball resting upon a table is in neutral equilibrium; for when it rolls the height of the centre of gravity is not changed.

Conditions of Stability of Suspended and Resting Objects.—The centre of gravity is in every case below the point of support when the suspended object is in equilibrium. The greater the distance between the point of support and the centre of gravity the greater is the tendency to return to the position of equilibrium.

When the centre of gravity and the point of support of a suspended object are close together the equilibrium of the object is easily disturbed. A good balance partly owes its sensitiveness to this condition, the centre of gravity and point of support being designedly brought close together.

It has been shown that in the case of a freely suspended object the centre of gravity is at its lowest point when the object is in equilibrium. Let us see how this applies to a body supported upon a surface below the centre of gravity.

A body is least liable to be upset when the centre of gravity is at a considerable distance from all parts of the edge of the base; for when this is the case the body has to be tilted through a large arc before the centre of gravity falls outside the base.

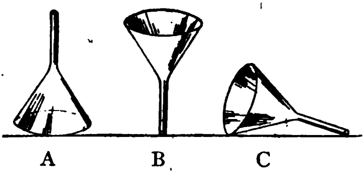


FIG. 116.—A funnel in (A) stable equilibrium, (B) unstable equilibrium, (C) neutral equilibrium.

A funnel standing upon its mouth is an example of a body which cannot be easily overturned on account of the low centre of gravity and its distance from the edge of the base (Fig. 116, A). It is then in stable equilibrium. If the funnel is stood upon the end of the neck it can easily be overturned, because very little movement is required to bring the centre of gravity outside the base. It is then in unstable equilibrium. When the funnel lies upon the table it is in neutral equilibrium, for its centre of gravity cannot then get outside the points of support.

CHIEF POINTS OF CHAPTER IX.

Centre of Gravity.—The point through which the resultant of the parallel forces, due to the weight of the individual particles of any mass, passes is known as the centre of gravity of the mass.

The centre of gravity of a body may be determined experimentally by allowing it to hang quite freely and when it has come to rest tracing a line through the point of support by means of a straight edge.

Plates of all shapes balance about their centres of gravity.

Positions of Centre of Gravity.—1. That of straight lines, circles, squares, and other regular figures, is at their geometrical centres.

2. That of a parallelogram is at the intersection of its diagonals.

3. That of a triangle is located on the line drawn from one of its angles to the middle point of its opposite side and at a distance of one-third of this line's length from that side of the triangle.

Equilibrium.—In a body at rest all forces acting upon it balance one another. It is in *stable equilibrium* when any turning motion to which it is subjected raises its centre of gravity; in *unstable equilibrium* when any such motion lowers its centre of gravity; and in *neutral equilibrium* when the height of the centre of gravity is unaffected by such movement.

QUESTIONS ON CHAPTER IX.

1. How would you determine the centre of gravity of an iron hoop made by joining together two semicircles, one thicker than the other? Explain how the observations could be used to find out which was the thicker half of the hoop.

2. How would you determine experimentally the centre of gravity of a sheet of cardboard of irregular shape?

3. What do you understand by the centre of gravity of a body?

4. Describe an experimental method for finding the centre of gravity of any body, *e.g.*, a waste-paper basket.

5. Where is the centre of gravity of a triangle located?

6. How could you find by a geometrical construction the centre of gravity of a circular plate, a square piece of cardboard, or any other geometrical figure?

7. When is a body said to be in equilibrium? Distinguish between stable, unstable, and neutral equilibrium. What is the condition which determines the nature of the equilibrium?

8. Describe an experiment which exemplifies each of the terms in the preceding question.

9. Give instances of bodies in stable, unstable, and neutral equilibrium.

10. A piece of cardboard, nine inches long and six inches broad, is divided into six equal squares by means of a ruler and pencil. One of the two squares that are not corner squares is cut away with a penknife. Find the centre of gravity of the remaining piece of cardboard.

11. A man with a bucket in one hand, stands with his feet close together. Why is it that in order to preserve his balance the man has to stand with his body leaning to one side. Illustrate your answer by a sketch.

CHAPTER X

WORK AND ENERGY

Work

EXPERIMENTAL WORK.

94. *Scientific Meaning of Work.*—(*a*) Place a three-cornered file upon a table so as to form a fulcrum for a strip, or rod, of wood (a foot-rule or ruler will do) to be used as a lever. Let the lever rest near one end of the file; place a mass of some kind upon this end. No work is done so long as the lever remains in this position. Raise the load by pressing down the free end of the lever. Work is now done because a force has acted through a certain distance.

(*b*) Suspend equal masses from the ends of a string passing over a pulley as in Fig. 88. The masses remain at rest and no work is done. Move one of the masses down; the other is pulled up, and work is thus done against gravity.

Work.—Newton's first law of motion teaches us that a body at rest is only set in motion by the action of a force upon it, and also that a moving body only changes the direction of its motion or its speed, as the result of the action of a force. When a body moves from rest the continued action of the force upon it causes an acceleration in the body.

In the case of a body already moving, though we have every right to argue that a change of direction or a change of velocity is the result of an external force, we cannot apply the converse statement and say that an external force acting upon a moving body causes a change of direction or of velocity, for in some instances the force may be entirely occupied in maintaining such motion in opposition to other forces acting upon it. Thus, when a ship is sailing with a uniform speed, the force of the wind is exhausted in maintaining this velocity by overcoming the resistance of the water.

When a force acts in either of these ways it is said to do **work**; that is, work is done by a force in setting a body at rest into motion and giving it a regularly increasing velocity; or, by maintaining a uniform motion in opposition to the action of other forces. We may class all these forces acting in opposition to the force which is being considered under the inclusive name of *resistance*.

We shall thus obtain for our definition of work the following statement:—**Work is done by a force, either when it acts upon a body producing an acceleration in its velocity, or when it maintains a uniform velocity in a body in opposition to resistance.** Or, more briefly, **Work is done when the point of application of a force moves.** A little consideration will convince the student that all instances of mechanical contrivances by means of which work is accomplished, come within the scope of our definition, as well as all other cases when we say in ordinary language that work is done. Take, for instance, a horse drawing a heavy weight along a road. Here the force exerted by the horse is used up in overcoming the resistance due to the road. A man raising a mass from the ground overcomes the resistance due to the body's weight. A body falling from a height under the influence of the earth's attractive force has work done upon it, with the result that its velocity increases according to a uniform acceleration of 32·2 feet per second in every second.

Measurement of Work.—Referring to our definition of work it would seem as though we had two kinds of work to measure, viz., the *work of acceleration* and the *work against resistance*. But since we can make a force perform either of these kinds of work according to the condition under which it acts, it is possible to measure either of them in the same units. An example will make this clearer. We can either allow a mass to drop from the hand and to move freely through the air with the uniform acceleration we have mentioned above until it reaches the ground; or we can attach the mass to a string, pass the string over a cylinder, and allow it to move towards the earth with a small uniform velocity—a result which can be brought about by applying the necessary friction between the cord and the cylinder, that is by applying a resistance. The final result brought about is the same under both sets of conditions; but in the first case the work is of acceleration, while in the second it is work against resistance.

Unless there is motion no work is done. If we put a weight upon a table or shelf, so long as the weight remains in one place, it evidently does no work, though it is capable of doing work by reason of its elevated position.

For practical purposes the unit of work which is adopted is *the work done in raising the mass of one pound through one foot*, and it is called the **foot-pound.** This is not a strictly constant unit for it will be evident, in the light of what has been said about the weight of a body, that where the weight is greater the amount of work done will be greater. The unit of work will vary slightly in different latitudes in a precisely similar manner to that in which the weight of a mass varies.

It will have been noticed that the question of time does not enter into an estimation of the amount of work done. It is manifest that the same quantity of work is accomplished whether a day is spent in raising a weight to a given height from the ground or only a minute. If we introduce the time taken to perform the work we begin to consider what is called the **power** of the agent. We should measure this power by the quantity of work the agent can perform in a given time; or **power is the rate of doing work** and is measured by the work done in a second. Thus, engineers use the expression **horse-power**, by which they mean the rate at which a good horse works. James Watt estimated this at 33,000 foot-pounds per minute, or 550 foot-pounds a second.

Generally, then, to find the amount of work performed by any force, we multiply the value of the force (expressed in suitable units) by the space through which it acts (using the corresponding unit in measuring this quantity also). The following simple application of the rule will familiarise the student with the method for employing it:—

How much work is done when an engine of mass 12 tons moves a mile on a horizontal road, if the total resistance is equal to a retarding force of 10 lbs. weight per ton?

The total resistance equals $12 \times 10 = 120$ lbs. weight, the distance traversed is 5,280 feet.

$$\therefore \text{Work done} = (120 \times 5{,}280) \text{ foot-pounds.}$$

Energy.

EXPERIMENTAL WORK.

95. *Energy of Moving Bodies.*—(*a*) Stretch a piece of tissue paper over the top of an empty jam-pot or large pill-box. Carefully place a bullet on the paper and notice the paper will support it. Now lift the bullet and allow it to drop on to the paper. It will be seen that the bullet pierces the paper.

(*b*) Support a weight by a thin thread. Notice that though the thread will support a weight at rest it will be broken if the weight is allowed to fall.

(*c*) Observe that a falling weight attached by a string to a spring balance extends the balance beyond the point which it indicates when the weight is at rest.

Energy.—By the energy of a body we mean its power of overcoming resistance or doing work. All moving bodies possess energy. Moving air or wind drives round the sails of a windmill and so works the machinery to which the sails are attached; it drives along a ship, thus overcoming the resistance of the water. The running stream works the mill-wheel, and the energy it possessed is expended in grinding corn. The bullet fired from a rifle can pierce a sheet of metal by overcoming the cohesion between its particles.

All these examples are cases of the energy of moving bodies, or the energy of motion, or *Kinetic Energy*. **Kinetic Energy is the energy of matter in motion. All energy which is not kinetic is known as Potential Energy.** It is capable of becoming kinetic or active when the conditions become suitable. Imagine a mass raised from the ground and placed upon a high shelf. We know that to place the mass in this position we must expend a certain amount of work, which is measured by multiplying its weight by the height through which it is raised. Further, we know that just as soon as we release it from its position of rest, making it free to move, the mass will travel with an ever-increasing velocity until it reaches the ground. On the shelf the mass, by virtue of its position, possessed a certain amount of potential energy exactly equal to the work expended in placing it there.

Similarly, an ordinary dining-room clock, which is worked by a spring, affords us an example of potential energy. The wound-up spring possesses potential energy exactly equal to the amount of work done in winding it up. This potential energy is being continually converted into kinetic energy as it becomes unwound in working the clock.

The motion of a pendulum affords an interesting example of the two forms of energy. At the end of its swing in the position A (Fig. 117), the bob of the pendulum possesses potential energy enough to carry it through half an oscillation,[1] that is, until it reaches its lowest position N, when the whole of the energy of position which it possessed at A is expended, as it can reach no lower position. But though it lacks potential energy, since it is a mass moving with the velocity it has gained in its passage from A to N, it possesses energy of motion, or kinetic energy, enough to carry it up to its next position of rest at A′—where the only energy it will have will be again potential. Through the next oscillation from A′ to A it will pass through just the same transformations again.

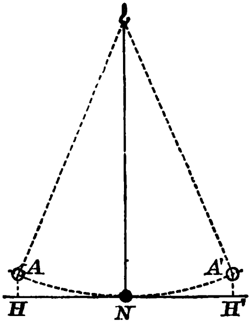


FIG. 117.—Pendulum in oscillation.

At any point in the swing the pendulum will possess a certain amount of energy due to position and a certain amount due to motion, but the total amount of energy—the sum of the potential and the kinetic energy—is always the same, the loss of one form of energy being exactly equalised by the gain of the other.

Forms of Energy.—A body may possess energy due to other causes than that of the actual motion of the body as a whole. When it is in rapid vibration, or when it is heated, or when it is electrified, it is endowed with energy in consequence of these conditions. But when a body is in rapid vibration it gives out sound or becomes a sounding body, hence we may regard sound as a form of energy. We shall see that work may be done by the passage of heat from a hot body to a cold one, and, in consequence, heat is properly regarded as another form of energy. An intensely hot body emits light, hence it would seem that light and heat have a common cause, and that we must also regard light, like heat, as a manifestation of energy. When a body is electrified it has the power of attracting unelectrified and certain electrified bodies also, and when such bodies are attracted as a result of this electrification, we see that electrification must similarly be looked upon as still another kind of energy. But it must be borne in mind that electrification is not electricity. Then, too, there is the attraction of magnetism, which is capable of accomplishing work, and hence must likewise be looked upon as a form of energy. Chemical combinations, again, are always accompanied by the development of heat, and resulting as they do from the chemical attraction of two more or less unlike forms of matter, we shall be right in saying chemical combinations are always accompanied by energy changes, and so in regarding chemical attraction as another kind of energy. **In addition to the energy of moving bodies we have energy manifested as sound, heat, light, electrification, magnetism, and chemical action.**

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[1] Some physicists regard the motion from A to A¹ as half an oscillation.

Bearing this in mind, it will perhaps assist the student to grasp the enlarged conception of energy which is here presented to him, if he regards *energy as being a capacity for producing physical change.*

Heat as a Form of Energy.

EXPERIMENTAL WORK.

96. *Heat appears when Motion is Destroyed.*—(*a*) Procure a piece of lead in the form of a sphere (about the size of a marble) with a neck or hook upon which a piece of string can be fastened. Tie a piece of string firmly to the neck, and while holding the string strike the sphere several times smartly on an iron plate. The sphere becomes warmer than it was before the experiment.

(*b*) Hammer a piece of lead, or saw wood, or bore a gimlet into a piece of wood, and test the temperature of the lead, saw, or gimlet, before and after the experiment.

(*c*) Rub a brass nail or button on a wooden seat, and notice its increase of temperature.

(*d*) Strike a match; it ignites in consequence of the heat developed by the friction.

97. *Heat often disappears when Motion is Produced.*—(*a*) Allow air, which having been compressed into a cylinder or bicycle tyre has again assumed the temperature of the air, to come in contact with a ther-

mopile; or other means of measuring changes of temperature, such as a delicate thermometer. Notice the cooling of the compressed air when allowed to escape.

Heat as a Form of Energy.—Heat was not always regarded in this way. It was originally thought to be a fluid called Caloric, and it was supposed that a piece of hot iron differed from a cold piece in having entered into some sort of union with this fluid. But, since the experiments of Rumford, we can no longer doubt that heat is not material, but a form of energy. Rumford boiled water by the heat developed by the friction between two metal surfaces which he rubbed together; and he found that the amount of water he could bring to the boiling temperature depended only on the amount of work he expended in rubbing. Since he could obtain an indefinite amount of heat from two definite masses of metal, it was quite clear that heat could not be matter, which, as we have seen, cannot be created. Davy made the truth even clearer, by obtaining heat enough to melt ice by simply rubbing two pieces of this solid together. They were both cold or without caloric; and since heat could be obtained by rubbing even these together, it was quite certain that heat could not be a fluid. Joule went a step further and measured the amount of work which must be done to obtain a given quantity of heat; or, as we say, he measured the **mechanical equivalent of heat.**

Some examples which will be familiar to the student will provide him with proofs of the statement that heat and work are convertible. When a brake is applied to the wheels of a train as it stops at a station, it is a common thing to see sparks fly. The resistance of friction which overcomes the motion of the train causes a sufficient amount of heat to be developed to raise the particles of steel, which get rubbed off, to a red heat. Similarly, when a bullet strikes a target, the heat is developed in consequence of the conversion of the kinetic energy of the bullet into molecular energy. By continually hammering a piece of iron on an anvil it can be made too hot to hold in the hand, the energy expended being converted into heat.

When we rub a lucifer match along a rough surface the heat into which the work is converted is enough to ignite the match. In all these cases mechanical work is converted into heat. The converse is true also; heat is convertible into work. In the steam-engine the heat of the furnace changes the water in the boiler into steam. The steam forces the piston along the cylinder, and this movement of the piston in a straight line is converted into the circular motion of a fly-wheel; or is used, through the intervention of suitable mechanism, in pumping water or performing some other kind of work. The steam which enters the cylinder is hotter than that which leaves it for the condenser. Thus, we see, part of the heat of the steam has been converted into useful work and parts of it have been lost to the condenser, the air, &c.

The Energy of Radiant Heat and Light.—We shall learn more fully later the reasons we have for regarding these as being of the same nature. We refer under this heading to those forms of energy which travel through space where, as we know, there is no air to convey them in the way in which sound is transmitted. But in order to understand the transmission of these forms of energy it is necessary to imagine the existence of a medium which is referred to as the luminiferous ether, or more shortly as the "ether." Certain experiments and observations by different investigators leave no doubt of the existence of this medium, vibrations in which cause light and radiant heat. Sound passes through air by the to and fro vibration, in turn, of the air particles, in the form of a *wave* as it is called. So radiant heat and light pass through the ether by the successive motions of the constituent molecules of the ethereal medium.

This takes place with astonishing quickness, for light travels about 186,000 miles per second, or something like 7½ times round the earth in this small interval of time. Nor does the ether fill inter-stellar space alone, for it must exist in the interstices of those bodies through which radiant heat and light can pass, or how else can light pass through a transparent body, or radiant heat through substances like rock-salt?

Radiation can be converted into work, but in a less direct manner than is the case with ordinary heat. It must first be absorbed, and heat some material body causing its molecules to oscillate in the manner we have described. This form of heat, we have seen, has a mechanical equivalent, and we can fairly argue that, if the whole radiation is absorbed, the mechanical equivalent of the absorbed heat is an exact measure of the energy of the radiation.

The Energy of Electrification and Electricity in Motion.

EXPERIMENTAL WORK.

98. *Energy of Electrification.*—(*a*) Suspend a pith-ball by a silk thread to a bent wire, as is shown in Fig. 118. Rub a rod of sealing-wax with fur and touch the pith-ball with the rod. Notice that after the contact it is impossible to make the ball come to the rod. They *repel* one another.

(*b*) Having touched the pith-ball with the rod of sealing-wax, which has been rubbed with fur as in the last experiment, bring near to it a rod of glass which has been rubbed with dry silk. Notice that the ball is *attracted* towards the glass rod.

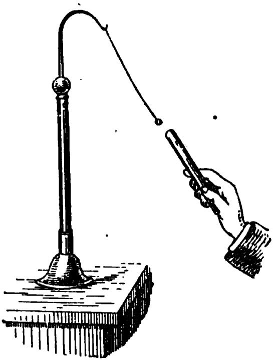

FIG. 118.—Electrical attraction.

99. *Energy of Electricity in Motion.*—(*a*) Examine an incandescent electric lamp. The passage of the electric current through the filament causes the filament to become white hot.

(*b*) If possible, connect the wires from the carbon and zinc poles of a Bunsen's battery to the ends of a thin piece of platinum wire. Notice that when the circuit is closed the platinum wire becomes red hot.

(*c*) Remove the platinum wire of the last experiment and twist the copper wires together. Hold the connected wires above a magnetic needle, and notice that the needle is set in motion.

Energy of Electrification.—We are careful not to speak of electricity as a form of energy, for whatever electricity may be it certainly is not energy. Though it would be very interesting to discuss the nature of electricity it does not come within the scope of our subject. The experiments with the pith-ball show that we are right in regarding electrification as a manifestation of energy.

What is the significance of these experiments? In both cases the pith-ball moves through a certain distance under the influence of a force, in one case of repulsion, in the other of attraction, and in consequence work is done. In certain circumstances, as in the discharge of a Leyden jar, the energy of electrification becomes manifest in the form of a vivid spark and a slight explosive sound.

Electricity in motion constitutes what is known as the **electric current**, and of its capability of doing work the student has abundant evidence in the heat and light of an incandescent electric lamp, where the passage of the current through a wire, which offers considerable resistance to its passage, causes the wire to become sufficiently hot to be utilised as a source of light.

It will be very instructive to consider briefly the case where the electric current is formed as the result of chemical action in a battery, and is thence passed by wires to a lamp of the kind mentioned. This is the ordinary condition of things as already described ; but imagine the lamp left out and the battery made to work simply through an ordinary copper wire which presents little resistance. The current has no work to do beyond heating the wire, and the energy of the current is almost wholly expended in heating the liquids and other parts of the battery, which is of course a very undesirable waste of energy.

Instances of the conversion of the energy of the electric current into mechanical work will doubtless have come under the student's attention.

Other forms of energy can be converted into that of electrification and of electricity in motion. If certain crystals, *e.g.*, tourmaline crystals, are heated, it is found that they become electrified, one part of the crystal exhibiting electrification of the kind developed when sealing-wax is rubbed with fur, another exhibiting the kind obtained by rubbing glass with silk.

Heat can give rise to electric currents. If a piece of the metal antimony is soldered to a piece of the metal bismuth and heat is applied to the junction, it is found that an electric current passes from the bismuth to the antimony.

Energy of Chemical Action.

EXPERIMENTAL WORK.

Abundant instances of chemical action will be found in later chapters ; it will be sufficient to here give one or two simple cases.

100. *Heat Produced by Chemical Action.*—(*a*) Place a small piece of dry phosphorus[1] on a plate, and a short distance from it a few grains of

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[1] Great care must be used in handling phosphorus, as it is easily ignited.

solid iodine. Nothing happens. By means of a glass rod push the piece of phosphorus on to the iodine, and notice that when they come into contact the phosphorus inflames and dense fumes are formed, which, as will be understood after reading the chemical section of this book, are a compound of phosphorus and iodine.

(*b*) Notice the heat of the flame of the laboratory burner, where certain chemical actions are going on, which are described in a later chapter.

Energy of Chemical Action.—In speaking of heat as a form of energy we took the example of the work done by an engine as the result of the heat from the furnace ; but we can now push our inquiry a step further back. What causes the heat of the furnace ? Evidently the burning of the coal, which, as we shall learn, is nothing more than chemical action. The coal enters into a chemical combination with one of the constituents of the atmosphere, and in doing so, heat is evolved, as it is, indeed, in all cases of chemical combination.

But as we shall soon have occasion to study many cases of chemical action, we need not spend much space over the matter here, though it must be pointed out that, just as in all the other instances of energy we have studied, not only is it true that chemical action is accompanied by changes of energy, but also that it can result from these other forms. Light can be made to bring about chemical action, as it does in the case of the exposed photographic plate. Electric separation or the energy of electrification also causes chemical action, as will be seen later.

Transformation of Energy.—We have learnt that one kind of energy can cease to exist in that particular form, and can assume another condition. We have seen that the energy of moving bodies can give rise to sound and heat ; that heat can be changed into the energy of moving bodies, electric currents, and chemical action. Indeed, one form of energy can assume almost any other form. The general tendency of all forms of energy is gradually to get converted into heat. When this change has become complete and all the energy of the universe exists as heat at the same temperature, there will be no further transformations possible. Consequently no work of any kind will be possible, which means there will be no life, no movement of bodies from place to place, but universal calm

Conservation of Energy.—We have seen that matter cannot be destroyed; we have now to learn that **energy is indestructible.** The total amount of energy in the universe remains the same. One form may be changed into another, but we can create no new energy. We may be unable to trace and account for some of it in the numerous transformations which it undergoes, but we are sure, from many considerations, that if our methods of experiment were only refined enough, we should be able to account for the whole amount.

The great source of energy in the solar system is the sun. It is from the sun that we are continuously receiving streams of energy in the form of radiation, which are continually assuming the various other forms of energy we have considered. Returning once more to our steam engine, we have traced back the work it does to the chemical combination of the coal with a part of the atmosphere. Or, putting the case in another way, we have seen that there exists a certain amount of potential energy in the coal and atmosphere which is capable of becoming kinetic as soon as the temperature at which the coal can combine with oxygen has been reached. Whence comes the potential energy of the coal? Coal results from the compression of vegetable material which lived and flourished on the earth ages and ages ago. This vegetable material formed the tissues of mosses and other similar plants, which in the presence of sunlight have the power, by virtue of the green colouring matter they contain, of decomposing one of the gases of the atmosphere, carbon dioxide, splitting it up into its elements, carbon and oxygen, reserving the former for themselves and returning the latter to the air.[1]

This carbon unites with the elements of water (contained in the plants) forming compounds which build up the tissues of which the plant is constructed. The tissues of the plant represent from our point of view the work done in splitting up the carbon dioxide by absorbing the energy of radiation. They still represent this energy when they have assumed the condition of the coal, and it is in this sense that coal is poetically referred to as "bottled sunshine."

If the earth receives so great an amount of energy from the sun, it is easy to understand that the total quantity of energy which is given out by the sun must be enormously greater. But this radiation from the sun's surface is continually going on; that is, the sun is constantly losing energy, and this cannot go on indefinitely without the loss being made good. How is the energy of the sun maintained? It has been suggested that the heat generated by the impact of the meteorites which fall upon the sun in great numbers is capable of accounting for this energy; and that in addition to this a slight shrinkage of the sun's mass in cooling evolves a large amount of energy. But interesting as this subject is we cannot pursue it further here.

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[1] The student must remember to re-read this after studying the Chemistry Chapters.

CHIEF POINTS OF CHAPTER X.

Work is the act of overcoming resistance, or causing change of velocity.

The Principle of Work.—Work is done by a force when the point of application moves through any distance.

Work done = force × distance.

A Foot-pound is the work done when a force equal to the weight o one pound is exerted through a distance of one foot in the direction of the force.

Power, or the rate of doing work, is measured by the number of foot-pounds produced in a given time. A *horse-power* is equal to 33,000 foot-pounds per minute.

Energy is the ability to do work.

Energy.

Kinetic, due to motion, shown by a moving cannon ball and a flowing river.	Potential, due to position, as a mass at the top of a tower and a wound up spring.

Manifestations of Energy.

- *Heat*, produced by motions of molecules.
- *Radiation*, due to vibration set up in the ether, and producing the effects of radiant light, heat, &c.
- *Electrification*, evidenced by the action of electrified bodies upon one another.
- *Electricity in motion*, as in the electric current, which can be transformed into light, heat, or motion.
- *Chemical action*, used to produce light and heat when a fire burns, and to produce motion in a gas-engine,

Conservation of Energy.—Energy is never lost, but only changed in form, and whatever transformations take place, the sum total of kinetic energy and potential energy remains the same.

QUESTIONS ON CHAPTER X.

1. Energy may be defined as the ability to do work. Give instances to show that heat, electricity and chemical action are forms of energy thus described.

2. When a brake is applied to a wheel of a moving train, red-hot sparks are seen. What are these sparks, what is the source of their heat, and why do they soon disappear?

3. How would you prove that the destruction of the visible motion of a body is often accompanied by the appearance of heat?

4. Define the meaning of the word "energy," and give three or four examples to prove that a moving body possesses energy.

5. Name some forms of energy, and give instances of transformation of energy from one form to another.

6. In the case of a shot fired at a target, state (*a*) why the velocity of the shot changes; and (*b*) why the target is made hot where the shot strikes it.

7. Define work, and describe an experiment to prove that a falling ball is capable of doing work.

8. Explain the terms power of an agent and horse-power.

9. Describe an experiment which indicates that "Heat is a form of Energy."

10. How would you prove that "when bodies are electrified they are endowed with energy and can produce motion and heat"?

11. Define the meaning of the word "energy," and give three or four examples to prove that a moving body possesses energy.

12. What is the meaning of the terms velocity, mass, force, work, energy, inertia?

13. Explain the terms "foot pound" and "horse-power." How much work is done in raising 25 weights of 56 lbs. each from the ground to a height of 4 feet?

14. The point of a gimlet with which a hole has been bored is found to be hot. How do you explain this? Give other instances of the same sort.

15. Describe experiments to show that energy of motion can be converted into heat.

CHAPTER XI

EFFECTS OF HEAT. THERMOMETERS.

Effects of Heat.—If we make a thing hotter and hotter, we are able to notice several changes in it. These changes are of three kinds, namely:

(1) Change of size; (2) Change of state; (3) Change of temperature.

Change of Size.

EXPERIMENTAL WORK.

101. *Expansion of Solids.*—(*a*) Procure an iron or brass rod about six inches long which fits into a "gauge" cut out of a sheet of thin brass, as shown in Fig. 119. Observe that the metal rod just fits the gauge. Heat the rod by a spirit lamp or laboratory burner. The rod is now too large to go into the gauge.

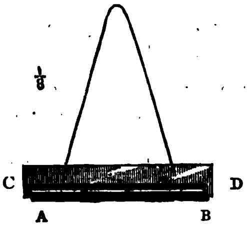

FIG. 119.—The rod *A B* will fit into the gauge *C D* when it is cold, but it is too large when hot.

(*b*) Place a heavy mass on one end of the iron bar resting upon one of two blocks, as in Fig. 120. Let the other end bear upon the needle placed upon the other block and having the straw pointer fixed to it. Heat the bar with a flame and notice that the pointer moves on account of the expansion of the iron.

(*c*) Solder together side by side a brass wire and an iron wire, each about two feet long. Hammer the compound wire straight, and notice how it bends when heated.

(*d*) Fuse a piece of platinum wire through the side of a glass tube, and notice that the glass does not crack on cooling. The platinum and glass expand about the same amount for a given increase of temperature.

102. *Expansion of Liquids.*—(*a*) Procure a 4 oz. flask and fit it with a cork. Bore a hole through the cork and pass through it a long glass tube which fits tightly. *Fill* the flask with water coloured with red ink. Push the cork into the neck of the flask and so cause the coloured water to rise up the tube. See that there is no air between the cork and the water. Now dip the flask in warm water, and notice that the liquid gets larger and rises up the tube (Fig. 121). Take the flask out of the warm water, and see that the coloured water gets smaller as it cools and that it sinks in the tube.

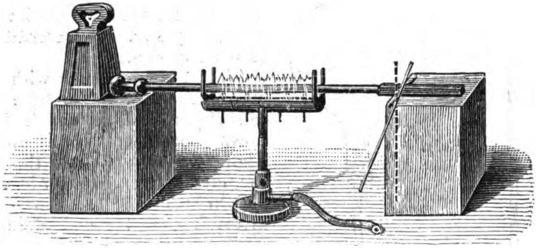

FIG. 120.—A flat bar of metal having one end kept from moving by a heavy mass is heated, and the other end moves the pointer, because the bar gets longer.

(*b*) Fit with corks the necks of three 4 oz. flasks. Fit tightly into the corks three narrow glass tubes open at both ends. Fill the flasks with water, alcohol, and oil of turpentine respectively. Push in the corks till the liquid stands in each tube at the same height. Put all three flasks to the same depth into a vessel of warm water. Notice that the expansion of the glass causes a momentary sinking of the liquids; and that ultimately the expansions are very different.

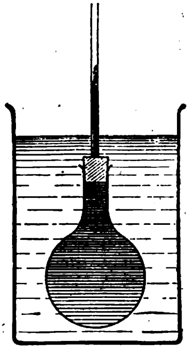

FIG. 121.—The expansion of a liquid.

103. *Expansion of Gases.*—(*a*) Procure a well-made paper bag and tightly tie a piece of tape round the open end. Hold the bag in front of the fire and notice that the air inside gets larger and inflates the bag.

(*b*) Or, obtain a flask with a cork and tube, as in Fig. 122. Remove the cork and tube, and, by suction, draw a little red ink into the end of the tube near the cork. Re-insert the cork and gently warm the flask by clasping it in your hands. Notice that the air in the flask gets larger and pushes the red ink along the tube.

(*c*) Turn over and place the open end of the tube beneath the surface of some coloured water in a beaker. Warm the flask with the hand or a flame so as to expel some of the air, and let the liquid rise in the stem, Fig. 122. This constitutes an *Air Thermometer.*

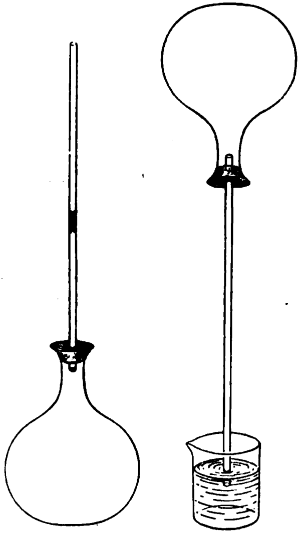

FIG. 122.—Experiments to show the expansion of air by heat.

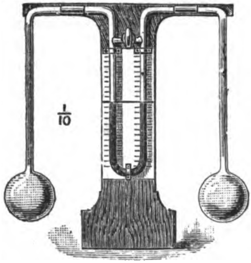

FIG. 123.—A simple form of differential thermometer.

(*d*) Fit a 2 oz. flask with a tight cork through which a tube passes, the upper end of which is bent down and then up at the end. Clamp the flask so that the end of the tube dips under water in a basin. Fill a test-tube with water, and invert it over the end of the tube. Warm the air in the flask, and collect the expelled air in the test-tube.

(*e*) Fasten two bulbs or flasks together (air-tight) by a tube bent six times, at right angles, and containing some coloured liquid in the middle bends Fig. 123. Show that the liquid moves if one flask is warmed more than the other. (This instrument is known as a *differential thermometer.*)

Change of Size. Expansion.—As a rule all bodies, whether solid, liquid, or gaseous, get larger when heated, and smaller when cooled.

The change of size which a body undergoes is spoken of as the amount it expands or contracts ; or heat is said to cause expansion in the body. This expansion is regarded in three ways. When we are dealing with solids, we find we obtain expansion in length or linear expansion, expansion in area or superficial expansion, and expansion in volume or cubical expansion. In the case of liquids and gases, we have only cubical expansion. Similar terms can be used with reference to contraction.

The expansion which substances undergo when heated has to be allowed for in many things. Railway lines, for instance, are not placed close together, but a little space is allowed between the ends of each length of the rails, so that the rails can expand in summer without meeting. Steam pipes used for heating rooms are also not firmly fixed to the walls at both ends, but are left slightly loose or are loose-jointed, so that they can expand or contract without doing any damage. For the same reason the ends of iron bridges are not fixed to the supports upon which they rest. Iron tyres are put on carriage wheels by first heating the tyre and, while it is hot, slipping it over the wheel. As it cools it contracts and clasps the wheel very tightly.

The common occurrence in domestic life of the cracking of thick glasses when boiling water is poured on them, is to be explained by this expansion of solids by heating. The part of the glass with which the hot water comes into contact is heated and expands, but the effect is quite local, the heating is confined to one spot because glass does not allow heat to pass readily through it. It is this local expansion of the glass which results in the cracking of the vessel.

Change of State.

EXPERIMENTAL WORK.

104. *Change of State produced by Heating.*—(*a*) Melt wax or lead in an iron spoon.

(*b*) Refer to experiments 17–21 on Change of State.

Change of State.—It has been explained in Chapter I. that substances exist in three states, namely, solid, liquid, and gaseous. By the action of heat a substance may be changed from one state to another. Wax, for instance, is usually a solid, but by heating it it becomes a liquid. Butter can in the same way easily have its state altered from solid to liquid. Lead and zinc are also melted when heated, but they require a hotter flame than wax or butter.

A good example of the changes of state produced by heat is obtained by heating a piece of ice until it becomes water, and then heating the water until it passes off into steam or water vapour. Here the same form of matter is by heat made to assume three states; in other words, ice, water, and steam are the same form of matter in the solid, liquid, and gaseous state respectively.

Change of state includes changes in the physical condition known as liquefaction or becoming liquid, and vaporisation or becoming converted into vapour. Thus, if we heat ice it first liquefies or becomes water, and is then vaporised or becomes steam.

In a later chapter we shall have to return to the study of this "Change of State," and consider the *amount of heat* which is necessary to effect the changes we have briefly described.

Temperature and Thermometers.

EXPERIMENTAL WORK.

105. *The Sense of Feeling may be Deceived.*—Arrange three basins in a row (Fig. 124); into the first put water as hot as the hand can bear, into the second put lukewarm water, and fill the third with cold water. Place the right hand into the hot water and the left into the cold, and after half a minute quickly put both into the lukewarm water. The right hand feels cold and the left hand warm while in the same water.

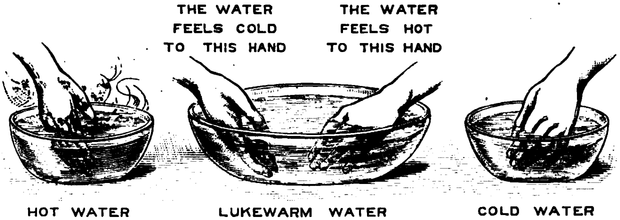
THE WATER FEELS COLD TO THIS HAND
THE WATER FEELS HOT TO THIS HAND
HOT WATER
LUKEWARM WATER
COLD WATER

FIG. 124.—The sense of feeling cannot be depended upon to tell the temperature of anything.

106. *Measuring Temperature.*—(*a*) Place the flask of water, with fitted tube used in Experiment 102 (*a*), in hot water (Fig. 121), and

notice the height of the liquid in the tube. Transfer it to cold water, and observe that the liquid in the tube sinks.

(*b*) Procure an empty thermometer tube, with a bulb at one end. (If a blowpipe is available a bulb can easily be blown upon one end of the tube by melting the glass in the flame, and blowing down the open end while the other end is molten.) Heat the bulb, and while it is hot dip the open end in mercury. As the bulb cools mercury will rise in the tube to take the place of the air driven out by the heat. Repeat the operation until the mercury fills the bulb and part of the stem.

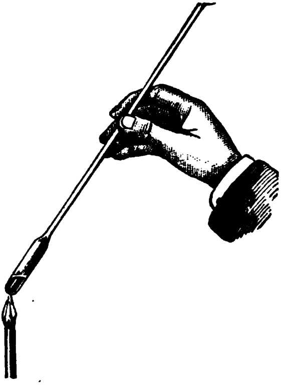

FIG. 125.—After heating the bulb as shown, the open end of the tube is placed in mercury, which rushes in and fills the bulb and tube.

(*c*) Place in hot water the bulb of the instrument just constructed, and make a mark at the level of the mercury in the tube. Now place the instrument in cold water, and notice that the mercury sinks in the tube. The mercury is thus seen to expand when heated and contract when cooled, and if the glass were marked the degree of hotness or coldness could be shown by the position of the top of the mercury.

(*d*) Examine a thermometer. Notice that it is similar to the simple instrument already described, but the top is sealed up, and divisions or graduations are marked upon it, so that the height of the mercury in the tube can be easily seen. These divisions are called *degrees* (Fig. 126).

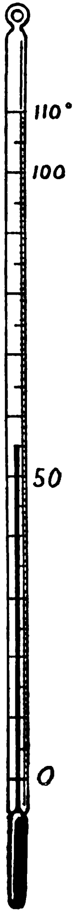

FIG. 126.)—A thermometer having degrees marked upon the stem.

Feeling of Heat and Cold.—Some people feel cold at the same time that others feel warm. You can therefore easily understand that the sense of feeling cannot be depended upon to tell us accurately whether the air or any substance is hot or cold. Some instrument is needed which does not depend upon feeling, and cannot be deceived in the way that our senses can. Such an instrument is called a **thermometer,** and it is used to measure temperature, that is, the degree of hotness or coldness of a body.

How Expansion may indicate Temperature.—You have already learned that substances usually expand when heated and contract when cooled. A flask filled with water, for instance, and having a stopper through which a glass tube passes, can be used to show the expansion produced by heat and the contraction by cold. But this flask and tube make but a very rough temperature measurer. The water does not get larger to the same amount for every equal addition of heat. Neither is it very sensitive, that is to say, it does not show very small increases in the degree of hotness or coldness, or, as we must now learn to say, it does not record very small differences of temperature, and for a thermometer to be any good it must do this. Then, too, as every one knows, if we make water very cold it becomes ice, which, being larger than the water from which it is made, would crack the tube. For many reasons, therefore, water is not a good thing to use in a thermometer.

Choice of Things to be used in a Thermometer.

1. *The substance used should expand a great deal for a small increase of temperature.*

Gases expand most, and solids least, for a given increase of temperature. Liquids occupy a middle place. The most delicate thermometers are therefore those where a gas, such as air, is the substance which expands. But in common thermometers a liquid, either quicksilver or spirits of wine, is used. Both these things expand a fair amount for a given increase of temperature, and, to make this amount of expansion as great as possible, they are used in fine threads by making them expand in a tube with a very fine bore.

2. *If a liquid is used it should not change into a solid unless cooled very much, nor into a gas unless heated very much.*

We cannot be sure of both these things in the same thermometer. When we want to use our thermometer for measuring great degrees of cold we use one containing spirits of wine, because this liquid has to be cooled a very great deal before it is solidified, that is, made into a solid. But we cannot use this thermometer for any great degree of temperature, because it is soon completely changed into a vapour when heated to only a comparatively small extent. If we wish to measure higher temperatures we use a quicksilver or mercury thermometer, because mercury can be warmed a good deal, or, as it is better to say, raised to a high temperature, without being changed into a gas.

3. *The liquid should be in a fine tube of equal bore with a comparatively large bulb at the end.*

We have seen that liquids have to be contained in some sort of vessel or else we cannot keep them together. We know, too, that we must have a fine bore, so that the liquid may appear to expand very much for a small change of temperature. The bore must be equal all the way along, that is, the width or diameter of the inside of the tube must be the same all the way along, so that a given amount of expansion in any part of the tube shall mean the same change of temperature, and, lastly, there must be a large bulb, so that there is a large surface to take the same temperature as that of the body the temperature of which we wish to measure.

Reasons why Mercury is used for Thermometers.—There are many reasons for selecting mercury as the liquid for an ordinary thermometer in addition to those already mentioned. It is a liquid the level of which can be easily seen; it does not wet the vessel in which it is contained; it expands a considerable amount for a small increment of temperature; it is a good conductor of heat, and consequently it very quickly assumes the temperature of the body with which it is placed in contact. Very little heat is required to raise its temperature, and there is therefore very little loss of heat due to warming the thermometer.

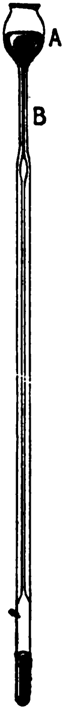

FIG. 127.—A stage in the construction of a thermometer.

Construction of a Thermometer.—Having selected a suitable piece of thermometer tubing, a bulb must be first blown on one end. The glass is melted at this end and allowed to run together and so close up the bore, and while the glass is still molten, air is blown down the tube from the other end, keeping the tube moved round, so that the bulb is symmetrically placed with reference to it. The bore of the tube is so fine that it is impossible to pour the liquid down it; some other plan must therefore be adopted. The tube is warmed and inverted in some of the liquid. The top of the tube is usually blown into a funnel shape as shown at A in Fig. 127, and liquid with which the thermometer is to be filled is put into it. Let us suppose mercury is being used. Warming the tube makes the air inside it expand, and of course some is driven out. As the tube cools the mercury is forced in by the weight of the atmosphere to fill the place of the expelled air. By repeating this alternate process of warming and cooling, in the circumstances we have described, enough mercury is soon introduced into the tube. The next step is to seal up the tube, leaving no air above the mercury; to do this the bulb is heated to a temperature slightly higher than that which the thermometer will be used to register. The mercury expands, and when it has reached the drawn out part, B, of the tube, a blowpipe flame is directed against it, and the tube is thus closed up. This method of closing a tube and keeping the air out is called *hermetically* sealing it. The thermometer at this stage should be put on one side for some days at least, in order that it may assume its final size, which it does very slowly indeed. The thermometer will now look like one of those in Fig. 128, according to the shape of the bulb which has been blown.

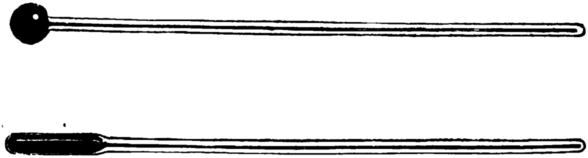

FIG. 128.—Thermometers before graduation.

Graduation of Thermometers.

EXPERIMENTAL WORK.

107. *The Temperature of Melting Ice.*—(*a*) Take some pieces of clean ice in a beaker or test-tube and plunge a thermometer amongst them. Notice the reading of the thermometer; it will be either ***no degrees***

(0°) or very near it.[1] Warm the beaker or test-tube, and observe that as long as there is any ice unmelted the reading of the thermometer remains the same.

(*b*) Repeat the experiment with pieces of some other blocks of ice, and observe the important fact that the temperature of clean melting ice is the same in all your tests.

108. *Effect of adding Salt to the Ice.*—(*a*) Add salt to the melting ice, and notice that the thermometer indicates a lower degree of temperature.

109. *The Temperature of Boiling Water.*—(*a*) Boil some distilled water in a flask, test-tube, or beaker, and plunge a thermometer in the boiling water. Notice the temperature. Raise the thermometer until the bulb is just out of the water and only warmed by the steam. Again record the temperature. In both cases the reading is the same. It is either *one hundred degrees* (100°), or very near it, if you use a thermometer with Centigrade divisions.

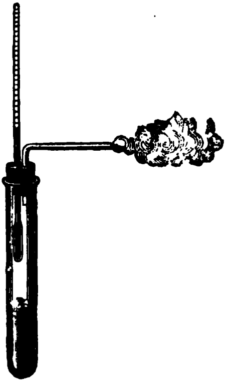

FIG. 129.—The water in the test-tube is boiling. Steam is coming out of the tube, and the thermometer is being heated by it.

(*b*) Repeat the experiment with a second lot of pure water, and note that the temperature of boiling water is again 100°.

(*c*) Add salt to the water. Hold a thermometer in the steam of the boiling water, and notice that the temperature is the same as before, namely, 100°. Push the thermometer into the water, and notice that a higher degree of temperature is indicated.

(*d*) Again place the thermometer in clean ice in a test-tube or flask. Gently heat the vessel, and notice the following changes:—

(1) The mercury remains at 0° until the ice is all melted.

(2) When the ice is melted the mercury rises gradually until it reaches 100°.

(3) The mercury remains stationary at 100° until all the water is boiled away.

110. *A Thermometer cannot be deceived.*—(*a*) Arrange three basins of cold, luke-warm, and hot water side by side. Place the thermometer in the cold water and then in the luke-warm water. Notice the temperature indicated in the luke-warm water. Now place the thermometer in the hot water, and when it has been there a minute or two put it into the luke-warm water. Notice that the temperature indicated is practically the same as before. It is thus seen that, unlike our sense of feeling, a

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[1] A centigrade thermometer is supposed to be used. If a Fahrenheit thermometer is used the reading will be 32°.

thermometer is not deceived by being made hot or cold before using it to indicate temperature.

(*b*) Notice the temperature of the room indicated by the thermometer.

(*c*) Place the thermometer in your mouth, and notice the temperature indicated by it at the moment it is removed.

Graduating the Thermometer—Fixed Points.—In the graduation of a thermometer the plan always adopted is to choose "two fixed points" from which to number our degrees of temperature. The most convenient lower fixed point we can get is the temperature at which ice melts, or water freezes, for this is always the same if the ice is pure, and remains the same as long as there is any ice left unmelted. Whenever the thermometer is put into melting ice the mercury in it always stands at the same level, or melting ice is always at the same temperature and may be thus used to give one fixed point. The "higher fixed point" chosen is that at which pure water boils at the sea-level. We have to make this stipulation, for the boiling point of a liquid is altered when the pressure upon it is changed, being raised if the pressure is greater and lowered if the pressure is less. When the water boils the temperature of the steam is the same as that of the water, and remains so as long as there is any water left. The lower fixed temperature we refer to as the "Freezing Point of Water," the higher as its "Boiling Point."

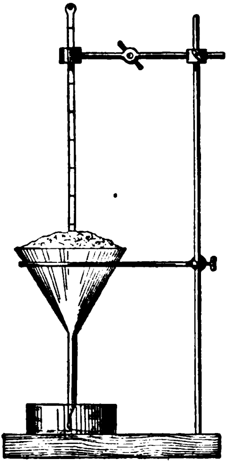

FIG. 130.—Determination of the temperature at which ice melts and water freezes.

Marking the Freezing Point.—For this purpose an arrangement like that shown in Fig. 130 is very suitable. The funnel is filled with pounded ice, which before powdering had been carefully washed; or snow might, if more convenient, be used. The glass dish catches the water which is formed from the melting of the ice or snow. A hole is made in the pounded ice by thrusting in a pencil or glass tube about the size of the thermometer, and into this hole the thermometer is put and is so supported that the whole of the mercury is surrounded by the ice or snow. The arrangement is left for about ten or fifteen minutes, until it is quite certain that the tube and mercury are at the same temperature as the melting ice. When this is so the tube is raised until the mercury is just above the ice, and a fine scratch made with a three-cornered file on the tube at the level of the mercury.

Marking the Boiling Point.—On account of the condensation of vapour upon the thermometer, the method used in Expt. 109 (*a*) to find the boiling point is not a very accurate one. More exact determinations can be made by means of the apparatus shown in Fig. 131. A can or flask *F* is fitted with a cork, through which a glass or brass tube *B* passes. Surrounding this tube is a wider tube *C*, fitted upon the inner tube by means of a piece of thick india-rubber tubing *D*. At the top of the outer tube is a cork *E* having a hole in which a thermometer can be fitted. When the water in the flask is boiled, steam passes up the inner tube *B*, and down the wide tube *C*, and escapes at the outlet *G* into the open air. To use the apparatus, the top of the stem of the thermometer is gently pushed into the cork which fits in the outer tube, and adjusted so that the 100° point is just below the cork. The cork is then fitted into its place, the water boiled, and when steam has been coming off for about a quarter of an hour, the thermometer is read. The observation is repeated after a few minutes, and when two readings obtained at an interval of about ten minutes agree, the point at which the top of the liquid stands is marked upon the stem. The temperature observed is the boiling point of water under the particular conditions existing at the time and place of the experiment.

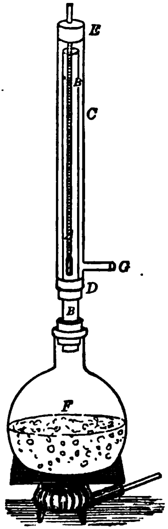

FIG. 131.—Apparatus for determining the boiling point of water.

Precautions Necessary in Marking the Fixed Points. *Freezing Points.*—Since Expt. 108 (*a*) has shown that the mixture of common salt with ice or snow lowers the temperature of the ice or snow, great care must be taken that pure clean ice is used when the lower fixed point of a thermometer is being marked. It must also be noted that the presence of substances other than common salt similarly have an effect on the temperature.

Boiling Point.—It has also been seen that the temperature of a boiling solution of common salt in water is higher than that of the steam which is given off from it. Moreover, since it is the temperature of the steam from boiling water which alone remains constant at the sea-level (the nature of the containing vessel and the presence of substances in solution affecting the temperature of the liquid), in marking the higher fixed point of a thermometer the instrument should be surrounded by the steam and not placed in the liquid. It will be seen more fully later that an increase of atmospheric pressure, represented by an increased barometric height, raises the temperature at which water boils, hence the height of the barometer must be recorded when the higher fixed point is being marked.

Effect of Pressure on the Boiling Point.

EXPERIMENTAL WORK.

111. Boil some water in a flask and let it continue to boil for some minutes until you can be sure all the air is driven out of the flask. Remove the burner and quickly insert a well-fitting cork. Allow the flask to remain to cool for a few minutes, then turn it upside down on a suitable support and throw cold water on to the flask. Notice that the water again starts boiling vigorously, Fig. 132.

How the Boiling Point is affected by Pressure.—Though it has been stated in general terms that the temperature at which water boils is quite definite, this is only true when the pressure of the air is the same. Pressure has a great influence on the boiling point of a liquid. The weight of the atmosphere is, we know, very considerable, being at the surface of the earth equal to that of a mass of 15 lbs. on every square inch. In studying the pressure of the atmosphere it is seen that its amount upon an object depends upon the extent of the air above the object. This will evidently be less at the top of a mountain than at the bottom of a mine, and consequently the pressure of the air will be in the former situation less than in the latter. If we wish to boil a liquid, therefore, in those cases where the pressure of the atmosphere is great we shall have to heat the liquid more before the bubbles of vapour formed can escape at the surface than when the pressure is less. If we heat the liquid more, its temperature will get higher before there is any conversion into vapour, and consequently its boiling point will be higher when the pressure is greater. In finding the boiling point of a liquid we must therefore know the pressure of the atmosphere at that time and place.

Example of Water Boiling at a Lower Temperature under Diminished Pressure.—A very simple experiment convinces us that water may boil at a temperature considerably below 100° C. when the pressure upon its surface is diminished. All we have to do is to take a well-fitting, sound cork which tightly fits the neck of a round-bottomed flask. We then boil some water in the flask and allow it to continue boiling for some minutes so that all the air in the flask is driven out and its place taken by steam. The burner is then removed and the cork inserted into the neck of the flask as rapidly as possible. After standing to cool for a minute or two, when we know its temperature can no longer be 100° C. the flask is turned over and cold water poured upon its upturned under surface or a cold wet sponge is squeezed upon it as shown in Fig. 132. The cold water causes the steam in the flask to condense, and as no air can get in the pressure on the surface of the warm water is now less than it was before, and therefore the water is seen to boil quite briskly again.

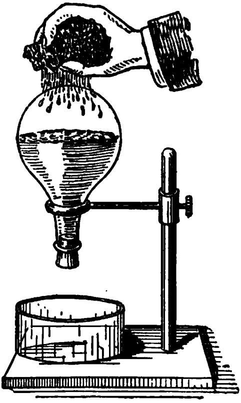

FIG. 132.—Water below 100° boiling under diminished pressure.

Thermometer Scales.—Some value must now be given to the two fixed points which have been obtained as previously described, and of course they could be called anything the maker likes, but for the sake of comparing one man's observations and experiments with those of other people it is most convenient to graduate all thermometers in the same way. The thermometers used in this country are divided up in two ways—(1) the Centigrade scale, (2) the Fahrenheit scale. A third scale—the Réaumur scale is extensively used in Germany.

The Centigrade Scale.—Here the freezing point is called *zero* or *no degrees Centigrade*, written 0° C. The boiling point is called *one hundred degrees Centigrade*, and is written 100° C. The space between these two limits is divided into 100 parts, and each division called a *degree Centigrade.*

The Fahrenheit Scale.—On thermometers marked in this way the freezing point is called *thirty-two degrees Fahrenheit*, written 32° F., and the boiling point *two hundred and twelve degrees Fahrenheit*, written 212° F. The space between the two limits is divided into 180 parts, and each division is called a *degree Fahrenheit.* The reason of this difference is interesting. The physicist Fahrenheit, after whom the thermometer is named, got, as he thought, a very low temperature, by mixing common salt with the pounded ice when measuring the lower fixed point, and he wrongly imagined that he had got the lowest temperature which could be reached, and called it zero.

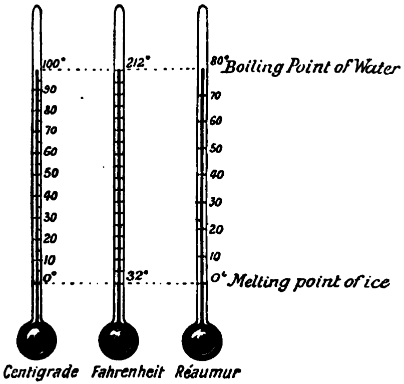

FIG 133.—Thermometer scales.

The Réaumur Scale.—Upon thermometers graduated according to this scale the freezing point is marked 0° and the boiling point 80°. The relation between the three scales is shown in Fig. 133.

Conversion of Scales.—It should be clear from what we have said that the interval between the boiling and freezing points, that is, the same temperature difference, is divided into 100 parts on the Centigrade scale and 180 parts on the Fahrenheit, and consequently 100 Centigrade degrees are equal to 180 Fahrenheit degrees, which is the same as saying one degree Centigrade is equal to nine-fifths of a Fahrenheit degree, or one degree Fahrenheit is equal to five-ninths of a degree Centigrade.

100 C. degs. = 180 F. degs. ; $\therefore$ 5 C. = 9 F. $\therefore$ C. = $\frac{9}{5}$ F. or F. = $\frac{5}{9}$ C.

In converting Fahrenheit readings into Centigrade degrees, we must subtract 32 (because of what has been said of the freezing point on the former scale) and multiply the number thus obtained by 5 and divide by 9. To change from Centigrade to Fahrenheit, multiply the former reading by 9 and divide by 5 and add 32 to the result.

EXAMPLE.—What temperature on the Fahrenheit scale corresponds to 20° C. ?

ANSWER.—20° C. is 20 C. degs. above the temperature of melting ice, *i.e.*, 20 × $\frac{9}{5}$ Fahr. degs. above 32° F. = $(36 + 32)^\circ$ F. = 68° F.

When it is necessary to refer to temperatures lower than the freezing point of water, a minus sign is placed before the temperature, thus, three degrees below the freezing point of water on the Centigrade scale is written -3° C.

CHIEF POINTS OF CHAPTER XI

Effects of Heat.—(1) Change of size. (2) Change of state. (3) Change of temperature.

Change of Size is known either as *Expansion* or *Contraction*. The former is generally brought about by heating, the latter by cooling.

Expansion by heat must be taken into account in: (*a*) laying railway lines, (*b*) fixing steam or hot-water pipes, (*c*) building bridges. It is utilised in fixing iron tyres to wheels.

Change of State is explained more fully in a later chapter.

Choice of Things to be used in a Thermometer.—(1) The substance used should expand a great deal for a small increase of temperature.

(2) If a liquid is used it should not change into a solid unless cooled very much, nor into a gas unless heated very much.

(3) The liquid should be in a fine tube with a comparatively large bulb at the end.

Reasons why Mercury is used for Thermometers.—In addition to those above (*a*) its level can be easily seen ; (*b*) it does not wet the vessel in which it is contained; (*c*) it expands a considerable amount for a small increment of temperature; (*d*) it is a good conductor of heat; (*e*) very little heat is required to raise its temperature.

The Fixed Points on a Thermometer.—(1) The temperature at which ice melts or water freezes; (2) the temperature of the steam issuing from boiling water when the barometer stands at 30 inches.

Thermometric Scales.—The distance between the marks of freezing and boiling points on the stem of a thermometer may be divided as follows:—

	Fahrenheit scale.	Centigrade scale.	Réaumur scale.
Boiling point	212°	100°	80°
Freezing point	32°	0°	0°

QUESTIONS ON CHAPTER XI.

1. What is a thermometer, and what information concerning heat does it supply?

Give an instance of each of the following effects produced by heat: (*a*) change of size, (*b*) change of temperature, (*c*) change of state.

2. How would you test whether the two fixed points on a mercurial thermometer were accurately marked?

What would be the effect on the values obtained for the fixed points of the presence of common salt as an impurity in the materials used in determining these points?

3. A flask containing pure water is heated by a single burner and one thermometer is placed with its bulb below the surface of the water, and another thermometer with its bulb just above the surface. When the water boils the readings of the two thermometers are taken. Will the readings be the same?

What will be the effect on the reading of each thermometer (1) of placing a second burner under the flask, and (2) of dropping some common salt into the flask?

4. Describe carefully the manner in which the freezing and boiling points on a thermometer are determined.

5. Describe experiments to prove the expansion by heat of (*a*) a solid, (*b*) a liquid.

6. In selecting a suitable liquid for a thermometer, what properties would you look for?

7. Why is mercury a suitable liquid for a thermometer?

8. What precautions are necessary in marking the boiling point of a thermometer?

9. Write a short account of two commonly used thermometric scales.

10. Take a glass tube open at one end, and having a bulb at the other. Hold the tube so that the open end dips into water. Heat the bulb gently with a spirit lamp for a minute or two, and then take the lamp away. What will be observed? How can you account for the facts observed?

11. Mention conditions that should be satisfied by the bulb and tube of a mercury thermometer. Give the reason for each condition that you state.

CHAPTER XII

HEAT AND TEMPERATURE

Distinction between Heat and Temperature.

EXPERIMENTAL WORK.

112. *Flow of Water.*—Using the apparatus described in Expt. 11, p. 7, squeeze the india-rubber with your finger and thumb. Pour water into the tube and wide glass vessel to different levels. Release the india-rubber tubing and notice there is a flow of water from the vessel where the water level is higher to the other. This continues until they are at the same level.

113. *Flow of Heat.*—Support a strip of copper about 12 in. long as shown in Fig. 134. Near one end place the top of a match or a small piece of phosphorus which has been cut off a stick kept under water, and afterwards dried. Heat the other end by a laboratory burner or spirit lamp. After a time the phosphorus catches on fire. Heat has passed from one end of the bar to the other, and if the heating is continued long enough, a certain stationary state analogous to the final level of the water in Expt. 111 is obtained.

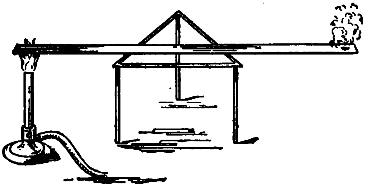

Fig. 134.—Experiment to show the flow of heat.

114. *Capacity for Water.*—(*a*) Arrange three glass cylinders, of different diameters but equal heights, in a row and pour a tumbler of water into each of them in succession (Fig. 135). Notice that the same quantity of water fills the cylinders to different heights. The level is highest in

the cylinder of smallest diameter and lowest in the one of largest diameter. The capacity for water of the one with the greatest diameter is evidently more than in either of the other cases, and that is why the level of the water in this cylinder is least.

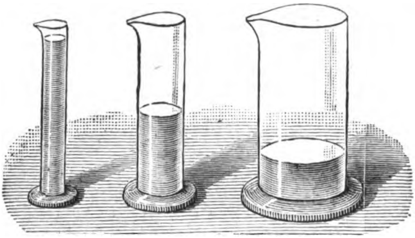

FIG. 135.—The same quantity of water produces different rises of level in vessels of different diameter.

(*b*) Now take cylinders of equal diameters and pour water into one of them to the height of four inches and into the other to the height of two inches. These two cylinders with the water in them can be said to represent a hot and a cold body. Now divide the water equally between the two cylinders by pouring water from the one in which the level is four inches to the other. Measure the height of the water in each cylinder—it is three inches. Remember that this number can be obtained by adding the two heights together and dividing by two.

115. *Capacity for Heat.*—(*a*) Mix 1 lb. of hot water, the temperature of which has been measured with a thermometer and recorded, with 1 lb. of cold water, the temperature of which is also recorded. It will be found on stirring them together with the thermometer (taking care not to break the thermometer) that the temperature of the mixture is midway between the two original temperatures.

(*b*) Mix 1 lb. of mercury at 100° C. with 1 lb. at the temperature of the room. Notice that the resulting temperature is midway between the temperatures of the two quantities of mercury.

116. *Difference of Capacity for Water.*—Arrange in a row two cylinders of the same diameter and two others—a wide one and a narrow (Fig. 136). But all the cylinders should be of the same height. Pour water into the two last until it is at the same level in each. Now the capacity for water of the last two cylinders is clearly unequal, and the level of the water is the same. Transfer the water in the wide cylinder into one of the two cylinders with equal diameters, and the water from the narrow cylinder into the other, and very carefully notice that the level of the water in the cylinder into which the liquid from the wide cylinder was poured is higher than that in the cylinder into which the liquid from the narrow cylinder was poured (Fig. 137.)

117. *Difference of Capacity for Heat.*—(*a*) Now take equal masses of lead and water in the same beaker, and heat them over a laboratory burner until the water boils; the temperature of both the lead and the water will then be about 100° C. Provide two beakers containing equal masses of cold water at the temperature of the room. Put the hot lead into one of these and the hot water into the other. Stir both mixtures and note the temperature in each case. The water into which the heated lead is plunged is not at so high a temperature as that into which the hot water was poured. Equal amounts of water at the same temperature are thus shown to be heated to different degrees by equal amounts of lead and water at the same high temperature.

Think over this and the last experiment and you will be led to the conclusion that lead and water have different capacities for heat, and correspond respectively to the narrow and wide cylinders.

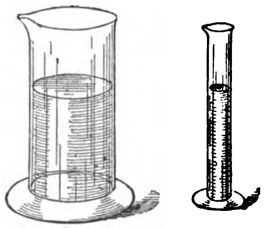

FIG. 136.—Equal levels of water but different quantities.

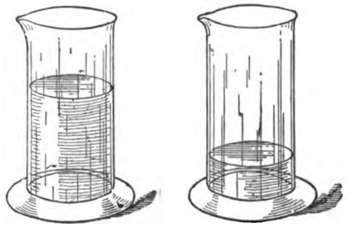

FIG. 137.—Vessels of equal capacity into which water from the jars Fig. 136 has been poured.

(*b*) Mix 1 lb. of water at the temperature of the air with 1 lb. of iron at 100° C., and notice the temperature of the mixture.

(*c*) Mix 1 lb. of water at 100° C. with 1 lb. of iron at the atmospheric temperature, and notice that the resulting temperature is in the latter case much the higher.

(*d*) Shake up known masses of water and mercury at different temperatures, and note the resulting temperatures. Repeat, using water and turpentine at known but different temperatures.

Confirm by shaking up mercury and turpentine.

The relative capacities for heat are inversely as the masses, and inversely as the change of temperature.

Difference between Heat and Temperature.—Temperature is not heat, it is only a state of a body, for the body may be cold one minute and hot the next. As you have learnt, a hot body is one at a high temperature, a cold body one at a low temperature. If a hot body and a cold body be brought into contact there is a passage of heat from the hot one to the cold until they are both of the same degree of hotness or coldness. Now, if in the last sentence we use the words "at a high temperature" for "hot," and "at a low temperature" for "cold," we shall easily be able to make up a definition of temperature. Thus, if a body at a high temperature and one at a low temperature be brought into contact, there is a passage of heat from the former to the latter until they are both at the same temperature. Hence, we can define temperature as **a condition of bodies that determines which of the two bodies when placed in contact will part with heat to the other.**

Similarity of Temperature and Water-Level.—It is well known that if two vessels containing water and arranged at different levels are connected by means of a piece of india-rubber tubing, there is a flow of water from the vessel of water at the higher level towards the vessel at a lower level. This is a consequence of a property possessed by all liquids which makes them, as we say, "*seek their own level.*" This flow of water continues until the water in the two vessels is at the same level. Evidently this is a similar state of things to that which we have in the case of a hot and cold body in contact. In one case there is a flow of water until the level is the same in the two vessels. In the other there is a flow of heat until the temperature of the two bodies is the same. **Temperature corresponds to water-level.**

Quantity of Heat.—Temperature, then, is not heat. Let us try and see more clearly what we mean by a quantity of heat. We can perhaps understand this best by considering a little more fully the case of the water in one of the vessels spoken of in the last paragraph. Imagine a cylinder of water; the most accurate determination of the height at which the water stands gives no information about the *quantity of water* in the cylinder. For a narrow cylinder will contain much less water than a broad one in which the water stands at the same level. Just as we can compare temperature with water-level, so we can similarly compare the quantity of water in a vessel with the quantity of heat in a body. We know very well that if we want to calculate the actual amount of water in a cylinder we must know, not only the height of the water, but also the size or

capacity of the cylinder. In precisely the same way, to ascertain the quantity of heat in a body we must know not only the temperature of the body but also its **capacity for heat.**

Comparison of Capacity of Bodies for Heat and Capacity of Vessels for Water.—Just as all vessels have not the same capacity for water, so all bodies have not the same capacity for heat. The same amount of water does not raise the level of water in vessels of different capacities to the same amount; nor does the same amount of heat raise the temperatures of equal masses of bodies having different capacities for heat through the same number of degrees of temperature.

The two quantities, namely, capacity for water and capacity for heat, can be still further compared. If the levels of the water in two cylinders of equal capacity be respectively four inches and two inches, and water be poured from the first to the second until the levels are the same in both, it is found by measuring that the final level is the average of the other two, or is equal to half the total obtained by adding the two levels with which we started together.

In a precisely similar way, if 1 lb. of water at a temperature of say 60° C. be mixed with 1 lb. of water at a temperature of say 20° C., and the temperature of the mixture be at once taken, it is found to be $\frac{1}{2}(60 + 20) = 40°$ C. So, too, if the level of the water in two vessels of different capacities be the same, and the water they contain be transferred into two other vessels, the capacities of which are the same, it is found that the level of the water in the second pair of vessels is by no means the same. The level is higher in that vessel which contains the water from the wider vessel.

Similarly, if equal masses of lead and water be heated to the same high temperature, say 100° C., and the lead be plunged into one mass of water at a lower temperature, say 20° C., and the hot water be mixed with another equal mass of water at 20° C., and the resulting temperatures in the two cases be determined, it is found that the temperature of the mass of cold water into which the hot water was poured is higher than that of the equal mass of cold water into which the lump of lead was plunged. Or, equal masses of lead and water at the same high temperatures cannot give out the same amount of heat when cooled, because they contain unequal amounts. The water at 100° C. contains a larger quantity of heat than an equal mass of lead at 100° C. because its capacity for heat is greater.

Or, if 1 lb. of water at the temperature of the air be mixed with 1 lb. of iron at 100° C., the resulting temperature is not so high as that obtained by mixing 1 lb. of water at 100° C. with 1 lb. of iron at the atmospheric temperature. This evidently means that 1 lb. of water at 100° C. contains more heat than 1 lb. of iron at 100° C., or the capacity of iron for heat is less than that of water. In the same way similar experiments with water and mercury show that the capacity of mercury for heat is less than that of water.

Capacity for Heat

EXPERIMENTAL WORK

118. Blacken two small beakers, of the same size, on the outside. Into one put a convenient mass of water at a known high temperature, and into the other an equal mass of quicksilver at the same high temperature. Into each plunge a thermometer. Allow both to cool, and notice that the quicksilver cools much more rapidly than the water. This is partly because the capacity of water for heat is much greater than the heat capacity of quicksilver.

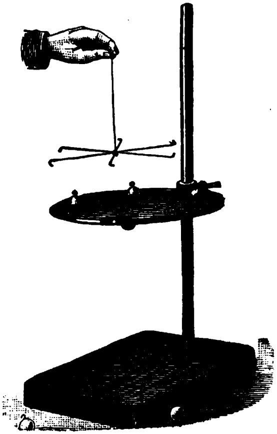

FIG. 138.—Experiment to show difference of capacity for heat.

119. *Experiment with Hot Balls and Wax.*—Take balls of different metals of, say, lead, iron, tin, bismuth, with hooks attached; also a cake of beeswax about ¼ in. thick, and arrange it on the ring of a retort stand as in Fig. 138. Then suspend the balls from a wire support (as shown) in a bath of oil heated to about 150° C., and drop them together on to the cake of wax; notice the iron ball melts through first, then the tin, followed by the lead, and last of all the bismuth.

120. *Unit of Heat Quantity.*—(*a*) Weigh about 200 grams of water into a beaker, and observe its temperature. Put the same amount into another beaker and heat it to about 70° C.; observe the temperature; take hold of the beaker with a duster, and quickly pour the hot water into the cold. Stir up the mixture with the thermometer and observe its temperature. Show in the manner

described on p. 181, that the number of units given out by the hot water as it cools is the same as the number taken up by the cold water as its temperature is raised.

(*b*) Repeat the experiment, using different masses of water at different temperatures. Show that the same fact holds true.

121. *Heat Capacities of Different Metals:* (*a*) *Iron.*—Weigh out about 50 grams of cold water and observe its temperature. Put into a test-tube an equal mass of iron tacks; stand the test-tube, with a thermometer surrounded by the tacks, in a beaker of water, and boil the water. Observe the temperature of the tacks, and when the water has been steadily boiling for some time, take out the thermometer and cool it under the tap. Quickly pour the heated tacks into the cold water, and observe the temperature of the mixture. Notice that it is not so high as when hot water is added.

(*b*) *Copper.*—Cut 50 grams of thin copper wire into pieces, and repeat the preceding experiment with them instead of with iron tacks. Compare, as before, the quantity of heat given up by the copper with that given up by the equal mass of water at the same temperature.

(*c*) *Lead.*—Repeat the preceding experiment with 50 grams of lead shot, and also with 50 grams of mercury.

These experiments show that equal masses of substances at the same temperature have very different quantities of heat in them; in other words, they have different capacities for heat.

Capacities of Water for Heat.—By finding the heating effect produced by equal masses of different substances at the same temperature, it can easily be shown that different bodies have different capacities for heat. But of all known substances, water has a greater capacity for heat than any other body. Consequently water will require a larger amount of heat to raise the temperature of a given mass of it through any number of degrees than an equal mass of any other substance. Similarly, and for the same reason, in cooling through any number of degrees of temperature a definite mass of water will give out a larger amount of heat than an equal mass of any other substance will in cooling through the same number of degrees.

Results in Nature of the High Capacity of Heat of Water.—The results in nature of this great capacity for heat which water possesses are very important.

Though water takes a large amount of heat to warm it and is consequently heated by the sun's rays only slowly, yet when it cools it parts with its heat just as slowly. The effect of this on the climate of islands is very marked. The winter temperature is never very low, and the climate never very severe, because the water surrounding the country acts like a great coat, and keeps it warm. Similarly, the summer temperature is never unbearably hot because the surrounding water takes so long to warm, and being always cooler than the land, keeps the temperature of the latter from getting very hot.

Illustration of Different Capacities for Heat of Various Substances.—If balls of lead, iron, tin, and bismuth are heated to the same high temperature in a bath of oil and placed together on a cake of beeswax, they melt through at different rates. The rate at which they melt through the wax depends chiefly upon the amount of heat they give out; so that since the iron gets through first it had most heat to give out, or its capacity for heat is greatest of all the metals taken. The experiment teaches, therefore, that the different metals have different capacities for heat. Though these bodies were at the same temperature, the amounts of heat they took up from the oil differed because of their different capacities for heat, and in the same way the amount of heat they are able to give to the wax also differs in the same proportion.

Unit Quantity of Heat.—Now we have learnt that we may correctly speak of quantities of heat, it is time that we considered how such quantities of heat are measured. As in all other cases of measurement we must have a unit or standard quantity with which to compare the quantities of heat we wish to measure. The unit quantity of heat which is generally adopted is the **amount of heat necessary to raise the temperature of one gram of water through one degree Centigrade.** This unit is called a **calorie.** The amount of heat required to raise the temperature of two grams of water through 1° C. will be two units or two calories. Similarly, the amount of heat necessary to raise the temperature of one gram of water through two degrees will be two units. The rule for obtaining the number of units of heat taken up by any mass of *water* as its temperature rises, or the amount given out by a mass of *water* the temperature of which is falling, is to multiply the number of grams in its mass by the number of degrees, as measured by a Centigrade thermometer, through which its temperature rises or falls. Or, we may express it thus:—

$$\text{Number of heat units} = \left\{\begin{array}{l}\text{Mass of water in grams} \times \text{Num-}\\ \quad\text{ber of degrees Centigrade}\\ \quad\text{through which its temperature}\\ \quad\text{rises or falls.}\end{array}\right.$$

It will perhaps be well to take an example or two to make the application of this statement quite clear.

Example 1.—Ten grams of water at 20° C. are heated until the temperature of the water is 70° C. How many heat units have been expended in the process?

Here the temperature has been raised from 20° C. to 70° C., or through 50° of temperature.

The mass of the water is 10 grams. Hence,

$$\left.\begin{array}{l}\text{Number of heat units used}\\ \quad\text{up in raising the tem-}\\ \quad\text{perature of the water}\end{array}\right\} = 10 \times 50 = 500 \text{ heat units.}$$

Example 2.—The temperature of 100 grams of water falls from 90° C. to 30° C. How many units of heat are given out?

$$\left.\begin{array}{l}\text{Number of degrees through}\\ \quad\text{which the temperature falls}\end{array}\right\} = 90 - 30 = 60 \text{ degrees.}$$

Mass of water = 100 grams. Hence,

$$\left.\begin{array}{l}\text{Number of heat units given out}\\ \quad\text{by the water in cooling}\end{array}\right\} = 100 \times 60 = 6{,}000 \text{ heat units.}$$

Mixing Equal Masses of Hot and Cold Water.—When equal masses of hot and cold water, the temperatures of which are known, are mixed together and the temperature of the mixture is observed, it is easy to show that the hot water gives out the same number of heat units in cooling down to the temperature of the mixture as the cold water takes up in being warmed up to the temperature of the mixture. This would only be exactly true, however, if no heat were lost in warming the vessel containing the mixture. But since the vessel *is* also warmed, to be strictly correct, we ought to say that, supposing no heat to be lost in any way, the number of units of heat given out by the hot water in cooling to the temperature of the mixture is the same as that taken by the cold water and the vessel containing it, in being warmed up to the temperature of the mixture. Making use of what has already been learnt (p. 180), namely, that the number of heat units given out by a given mass of warm water in cooling through a certain number of degrees, or the number of heat units taken up by a given mass of cold water in being warmed through a certain number of degrees, can be obtained by multiplying the mass of the water in grams by the number of degrees of rise or fall in temperature, it can be shown that the statement in the beginning of the paragraph is easily proved. Suppose the results obtained by mixing equal masses of hot and cold water were as follows :—

Mass of cold water .... = 200 gms.
Mass of hot water .... = 200 gms.
Temperature of cold water .... = 15° C.
Temperature of hot water .... = 70° C.
Temperature of the mixture .... = 42½° C.
Number of degrees through which the temperature of the cold water was raised .... = 27½°
Number of degrees through which the temperature of the hot water was lowered .... = 27½°
Now gain of heat by cold water .... = 200 × 27½ units
and loss of heat of hot water ...... = 200 × 27½ units
and these results are evidently the same.

Mixing Unequal Masses of Hot and Cold Water.—If we have different masses of hot and cold water and as before imagine no heat is lost to the vessel, the same thing can be shown to be true.

Example.—120 grams of cold water at 20° C. are mixed with 200 grams of warm water at 80° C. and the temperature of the mixture is found to be 57½° C. In this case

Number of degrees through which the temperature of the cold water was raised .... = 57½° − 20° = 37½°
Number of degrees through which the temperature of the hot water was lowered .... = 80° − 57½° = 22½°
Therefore the gain of heat by the cold water .... = 120 × 37½ = 4,500 heat units.
The loss of heat by the warm water ... = 200 × 22½ = 4,500 heat units.

This again shows that the statement is true that what heat is lost by the hot water is gained by the cold water, supposing of course that we imagine the vessel itself does not get hot.

Capacity for Heat of Tacks, Copper-Wire, and Mercury.—When equal masses of water, tacks, copper-wire, and mercury at the same high temperature, that of boiling water, for instance, are each in turn stirred up with equal masses of cold water at the same temperature and in separate beakers, it is found the hot water raises the temperature of the mass of cold water in which it is placed through a larger number of degrees than either of the other substances raises the temperature of the mass of water into which it is placed. This is because the capacity for heat of water is greater than that of any of these (or any other) substances.

If we notice the temperature of the mixture formed in each of the cases supposed, namely, tacks and water, copper-wire and water and so on, and then calculate the number of degrees through which each has raised the temperature of the water into which it was put, we obtain a series of numbers which enables us to compare the capacities for heat of each of the substances experimented with. The substances arranged in the order of their capacities for heat stand thus :—

Tacks
Copper-wire
Mercury
Lead.

The amount of heat required to raise the temperature of one gram of a substance through 1° C. or the amount of heat given out by one gram of a substance the temperature of which falls through 1° C., in comparison with the amount of heat taken up or given out by an equal mass of water, is known as the **specific heat** of the substance.

CHIEF POINTS OF CHAPTER XII.

Temperature is a condition of bodies that determines which of the two bodies when placed in contact will part with heat to the other. Temperature corresponds to water level.

To ascertain the **Quantity of Heat** in a body, we must know not only the temperature of the body, but also its *capacity for heat.*

Water requires a larger amount of heat to raise the temperature of a given mass of it through any number of degrees, than an equal mass of any other substance.

Unit Quantity of Heat is the amount of heat necessary to raise the temperature of 1 gram of water through 1 degree Centigrade.

$$\text{Number of heat units} = \text{Mass of water in grams} \times \left\{\begin{array}{l}\text{Number of degrees}\\ \text{Centigrade through}\\ \text{which its temperature}\\ \text{rises or falls.}\end{array}\right.$$

The amount of heat required to raise the temperature of 1 gram of a substance through 1° C., or the amount of heat given out by a gram of a substance the temperature of which falls through 1° C., in comparison with water, is known as the **specific heat** of the substance.

Questions on Chapter XII.

1. If a pound of water at 100° C. is mixed with a pound of water at 0° C., the temperature of the mixture is 50° C. How would the result have differed if a pound of oil at 100° C. had been substituted for the hot water? Explain the difference.

2. Explain what is meant by specific heat. How would you show that equal weights of two different substances give out different amounts of heat when cooled through the same range of temperature?

3. What is the difference between temperature and quantity of heat? What experiments would you perform to show that equal masses of different substances when cooled through the same range of temperature give out different quantities of heat?

4. Draw some distinctions between heat and temperature.

5. Describe an experiment to show that different substances at the same temperature have different quantities of heat.

6. State precisely what is meant by the statement that the specific heat of mercury is ·033.

7. What will be the temperature of the mixture produced by mixing:—(*a*) 1 lb. of water at 0° C. with 2 lbs. of water at 90° C.? (*b*) 1 lb. of mercury at 10° C. with 1 lb. of mercury at 100° C.?

8. Give a short account of the effects in nature of the high capacity of water for heat.

9. What is the unit quantity of heat? How many units of heat are required to raise the temperature of 50 grams of water from the temperature of the room (15° C.) up to the boiling point?

10. Describe a differential air thermometer. How would you use it to investigate whether equal volumes of two different substances give out equal amounts of heat when cooled through the same range of temperature?

CHAPTER XIII

CHANGE OF STATE IN RELATION TO HEAT

Maximum Density of Water

EXPERIMENTAL WORK

122. *Density of Water at Different Temperatures.*—(*a*) Fill a density bottle with water at the temperature of the room and determine the mass of the bottle and the water it contains by weighing. Now suspend it by a piece of copper wire in a beaker of water in such a way that the stopper of the bottle is out of water (Fig. 139). Raise the temperature of the water in the beaker ten degrees. The water in the density bottle expands and some of it is forced through the hole in the stopper. When the required temperature has been reached, touch the top of the stopper with a piece of blotting paper and quickly remove it from the beaker. Notice that at the instant of removing the density bottle it is full of water. The water soon contracts and when it is at the temperature of the room, the density bottle is not full of water. When it has thus cooled again, determine the mass of the bottle and water. It is less than before. Therefore the same volume of water at the higher temperature has a smaller mass than at a lower temperature, that is, its density is less.

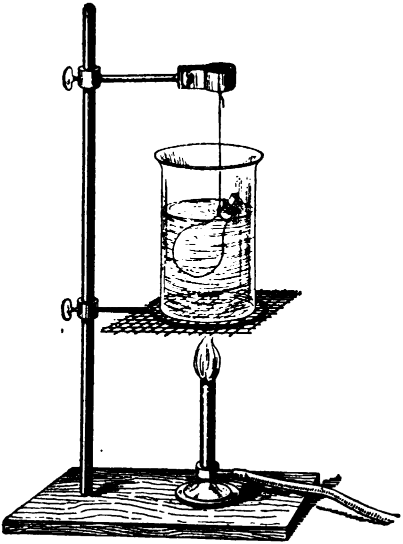

FIG. 139.—Determination of the density of hot water.

(*b*) Replace the bottle in the beaker of water and raise the temperature ten degrees higher than before. More water is lost by expansion. When cool weigh again.

Remember the masses of water obtained by subtracting the weight of the empty bottle are in the proportion of the density of the water.

123. *Anomalous Expansion of Water.*—(*a*) Procure or construct an apparatus of the form shown in Fig. 140. The cylindrical bulb should be about 10 cm. long and 1·5 cm. in diameter, and terminate in a capillary tube having a bore of about 0·5 mm. Heat the bulb; and let it cool with the open end of the tube inverted in mercury. By this means sufficient mercury (M) may be introduced to occupy about one-seventh the volume of the bulb. Then introduce in a similar way sufficient boiled distilled water to fill the remainder of the bulb and part of the stem. A short length of oil may also be introduced to prevent absorption of air and evaporation. A paper millimetre scale is then attached to the capillary tube.

Support this apparatus in a wide test tube containing mercury, so as to secure uniformity of temperature. Place a thermometer in the mercury, and support the wide tube containing it and the apparatus in a beaker of cold water. Notice the position of the top of the liquid in the tube, and read the temperature shown by the thermometer. Add ice to the water, and as the temperature falls notice the level of the liquid in the tube for every degree down to 1° or 2° C.

Then let the water in the beaker gradually rise in temperature, adding a little warm water if necessary, and again observe the positions at the same temperatures as before. The mean of the two positions observed for each temperature should be taken as the true reading for that particular temperature.

At what temperature has the water in the bulb the least volume, and therefore the maximum density?

(*b*) The changes in volume of water, when cooled down to freezing point, can also be observed by means of a test-tube of water having a good stopper, with a narrow glass tube in it instead of the bulb used in the preceding exercise. But as the expansion of water between 4° C. and 0° C. is very small, the experiment has to be carefully performed to be successful.

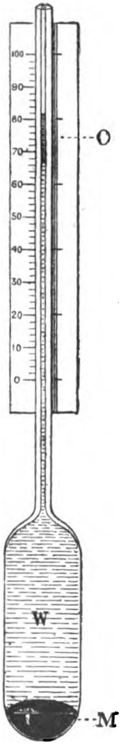

Fig. 140.—Apparatus for the determination of the changes of volume of water near the freezing point.

124. *Changes of Volume and Density accompanying Changes of State.*—Half fill a burette or graduated glass tube with paraffin oil. Put the burette in a jar containing ice and water until the temperature reaches

0° C. Observe the level of the paraffin oil in the burette. Gently drop in pieces of dry ice, and observe the volume of the ice added by noticing the rise of level of the oil. Let the ice melt, and when it is converted into water, again observe the reading of the burette; it will be less than before. This reading shows that the volume of water produced by the melting of a certain known volume of ice is less than the volume of ice. Find the ratio of the water produced to that of the ice from which it came. Hence the result will give you the density of ice.

125. (*a*) Fill a small narrow-necked bottle with water, and cork it up tightly. (A bulb blown at the end of a glass tube is better.) Place the bottle in a bowl and cover it with a freezing mixture of ice and salt. Carefully cover the bowl with a duster or cloth until you hear the bulb burst, then take off the covering and examine what has happened. Describe and explain the result of your experiment.

(*b*) Try to explain, from what you have learnt by your experiments, why water pipes burst in winter. How is it that the burst pipes are not found until the thaw sets in?

(*c*) Put a few pieces of ice in a glass of water. Does the ice float or sink? Is ice heavier or lighter than an equal bulk of water? How do you account for the difference of density between ice and water?

(*d*) Cut a piece of wax candle into chips, and put them into a test-tube. Melt the wax by gently heating the test-tube, and while it is liquid throw in it two or three small pieces. Do these pieces float or sink? Can you tell from your observations whether wax contracts or expands when passing from the liquid to the solid state?

126. (*a*) *Hope's Experiment to Determine the Density of Water.*—The changes of density of water near the freezing point can be indirectly observed by means of Hope's apparatus (Fig. 141), the principle of which is based upon the fact that the denser parts of a liquid sink and the lighter rise to the top. The apparatus consists of a glass or metal vessel having a trough surrounding the middle part. Two thermometers are inserted in holes near the top and bottom of the instrument respectively (Fig. 141).

The apparatus for performing this experiment can easily be made in a metal workshop. Holes are cut in the side of a tin canister, and short tin tubes are soldered into them. Corks for holding the thermometers are fitted into the tubes. For the trough a large tin canister is obtained and reduced to a convenient height. A hole is then cut in the bottom to permit the trough to fit upon the outside of the smaller canister. This must, of course, be done before the top tube is soldered on. To obtain the best results with

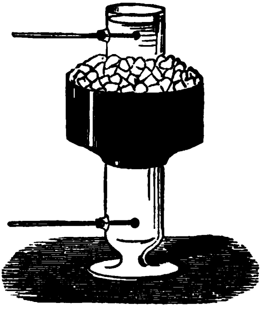

FIG. 141.—Hope's apparatus for determining the temperature of maximum density of water.

this or any other form of Hope's apparatus, the cylinder should be wrapped in cotton wool and stand on similar material; and the observer should only stand near it when he wishes to read the thermometer.

To use the apparatus the inner cylinder is filled with cold water—at a temperature of 6° C. to 8° C.—and the trough with a freezing mixture. The thermometers are then be read at intervals of a minute or two, and the results recorded.

At first the bottom thermometer will be most affected, while the top one remains at nearly the same degree of temperature. When the temperature of 4° C. is reached, the bottom thermometer remains steady, but the upper one commences to indicate a lower degree than before, and continues to go down until a temperature of 0° C. is reached if the experiment is continued long enough. Explain these changes, by means of the facts you have learnt as to the variations of the density of water with temperature.

Changes in Volume as Water is Cooled.—The first effect of cooling water is to make it get smaller in volume, or as we say, to contract. This goes on steadily until the temperature of four degrees Centigrade (4° C.) is reached. From this point, though we go on cooling the water, it no longer contracts, but begins to get larger or expand. This expansion continues until the temperature 0° C. is reached, when the water begins to change into solid ice, which is, as you have found, much larger than the water from which it is formed.

Changes in Volume as Water is Warmed.—If we had worked backwards, beginning with water at, say, 1° C., and had allowed it to get warmer, which it would do simply by being exposed to the air in the room, we should similarly notice that while it was being warmed up to 4° C. it would have steadily got smaller in volume, but after this temperature was reached it would get larger and larger as it got warmer and warmer.

Changes in Density as Water is Cooled.—It has already been learnt that if the volume of a body gets greater while its mass remains the same, what is called the density of the body must get less and less. It is quite clear that, if the same amount of matter occupies a larger space, it must be less closely packed into that space, and it is the closeness with which matter is packed into a space which we have learnt to call density. What changes in density take place when water is gradually cooled? Since we have seen in our experiments that the same mass of water gradually gets smaller and smaller in volume as it is cooled down to 4° C., we can now express the same fact in another way and say that its density becomes greater and greater as it is cooled down to 4° C. As from this temperature it gets larger as we continue to cool it, its density must get less and less. On the contrary, if we began with water at 1° C. and gradually warmed it, the density would steadily increase up to 4° C. and from that temperature upwards the density would regularly diminish.

Graphic Representation of Results.—A simple way of graphically showing the changes in volume which water undergoes when cooled is seen in Fig. 142. The water is represented as contained in a thermometer tube and the level of the water in the tube for each degree of temperature between 8° C. and 0° C. is shown. A glance makes the results of our experiments very plain. The size of the water is seen to get smaller down to 4° C. and then to begin getting larger, which it continues to do up to 0° C. So, too, the water is at once seen to be packed into a smaller space and consequently to get denser and denser as it is cooled down to 4° C. and then to become less dense as the lowering of temperature is continued. Or, you can use squared paper and represent the alterations in volume as you have learnt to represent similar changes.

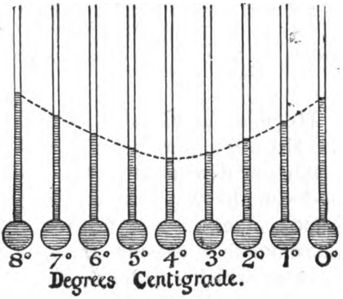

FIG. 142.—Contraction and expansion of water near the freezing point.

Along the horizontal line the consecutive degrees of temperature on the Centigrade scale are marked and numbered. The volume which the quantity of water experimented with has at each degree of temperature is represented, on a convenient scale, by the height of the vertical lines erected over the points representing the degrees of temperature. When the tops of these verticals are joined in by a continuous line you have a graphic representation of the various changes in volume experienced (Fig. 143).

The changes in density can be also represented by this plan. As before, the degrees of temperature are marked along a horizontal line, and the density at each consecutive degree is represented by the height of the perpendicular erected at these points (Fig. 144).

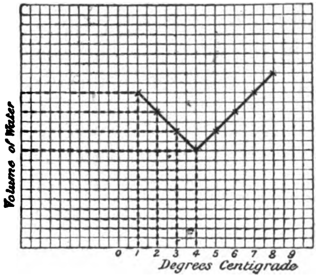

FIG. 143.—Changes in the volume of water near the freezing point.

Maximum Density of Water.—Because any mass of water has a smaller volume at 4° C. than at any other temperature, or what is the same thing, has a greater density at this than any other temperature, we speak of 4° C. as being the temperature at which water has its maximum density.

Hope's Apparatus.—An experiment with what is known as Hope's apparatus shows very well that water is at its maximum density at 4° C. A cylinder provided with two side necks in the way shown in Fig. 141 is filled with water at the same temperature as the air. Into the side necks, corks with thermometers passing through them are fitted. A freezing mixture, which can be made by mixing salt with pounded ice, is applied to the middle of the cylinder. This is done by filling a vessel, fixed round the middle of the outside of the cylinder, with the mixture in a way which the illustration makes quite clear. The freezing mixture, of course, at once cools the water in the middle of the cylinder. On watching the thermometers it is found that the first effect of the cooling is to cause the temperature of the lower thermometer to fall. The temperature of the upper thermometer, however, remains unaltered. The only way in which this can be explained is by supposing that as

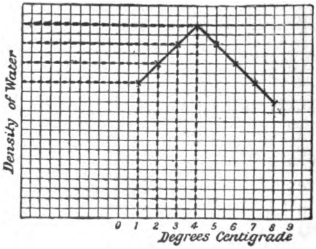

FIG. 144.—Changes in the density of water near the freezing point.

the water in the middle of the cylinder is cooled it gets colder and sinks to the bottom. As the cooling proceeds it is found that the water at the bottom of the cylinder *never gets below* 4° C. But soon after the water at the bottom of the cylinder has reached 4° C., the temperature of the upper thermometer begins to fall and goes on getting lower till it actually reaches 0° C. But all this time the water at the bottom remains at 4° C. Now it is quite clear that the densest water will sink to the bottom, and as the temperature of the water there remains at 4° C. it may be concluded that water at this temperature is denser than any other.

Expansion of Water as it Freezes.—When water is cooled down to 0° C. it changes into ice, and the ice which is formed takes up more room than the water does. Or, in forming ice the water expands. That this is really the case we can prove by quite filling a small vessel with water and inserting a nicely fitting cork, allowing no air to enter. If the tightly corked vessel is now placed into a mixture of ice and salt and the flask be left in this freezing mixture (as a precaution the vessel containing the freezing mixture and the flask should be covered with a duster), after a time a slight explosion is heard, and when the flask is uncovered and examined it is either found that the cork has been driven out, or, if the flask was not strong enough to bear the strain, it will be cracked and perhaps some ice may be found protruding from the neck or rent. The explosion is louder if a smaller cast iron cylinder with a top which screws on is used. This experiment has been tried on a large scale. Large bomb-shells have been completely filled with water, securely plugged, and left out a whole night during severe winters. In the morning some were found cracked all round the middle with a large belt of ice sticking out through the crack all round, and from others the plug had been forced out and a cylinder of ice was found sticking out where the plug had been inserted. Not only do we learn from such experiments as these that water expands in forming ice, but also that the force with which the expansion takes place is very great, being strong enough to rupture a bomb-shell. It is because of this expansion that we often have water-pipes bursting during frosty nights. The bursting of the pipe takes place when freezing occurs but is only discovered when the thaw takes place. This has given rise to a belief among some people that thawing causes the pipe to burst, but this is quite wrong.

Results in Nature of the Peculiar Expansion of Water.—Let us now try to apply what we have learnt about the way in which water behaves when it is cooled, and see what happens when the water of a pond is gradually cooled on a frosty night. As the temperature of the water at the surface gets lower and lower, the water there gets smaller and consequently denser. It therefore sinks and its place is taken by warmer water from below. The same cooling and sinking of the surface water continues until the temperature of the whole of the water is 4° C., at which temperature it has its maximum density, and consequently when the water at the bottom of the pond reaches this temperature it remains where it is. After the temperature of the water at the surface has reached 4° C., any further cooling causes it to expand and get lighter, and this result continues until 0° C. is reached and the water at the surface is changed into ice, which, being considerably lighter than water, remains on the surface. Ice, is, moreover, a very bad conductor of heat, and consequently the temperature of the water below the ice gets cooler very slowly and the thickness of the ice increases at but a small rate.

This condition of things prevents several disastrous consequences which would of necessity follow if ice were denser than water. If ice were denser than water, it would sink to the bottom of the pond at the moment it was formed, and as the frost continued, the ice would spread throughout the mass of the water, and not only would this result in the destruction of all the water animals in the pond, but it is more than probable that the heat of summer would be insufficient to completely melt it.

Heat Absorbed in the Fusion of Ice

EXPERIMENTAL WORK

127. *Melting Point of Wax.*—Melt a little paraffin wax in a beaker, and immerse the bulb of a thermometer in the liquid. When the thermometer is taken out, a thin film of liquid paraffin will be seen upon it. Let the bulb cool, and notice the temperature when the wax assumes a frosted appearance, indicating that it is solidifying. When the wax on the bulb has become solid, place the thermometer in a beaker of water

and gently heat the water. Observe the temperature at which the wax becomes transparent again. The mean of this result and the precedng one is the *melting point* of paraffin wax.

128. *Melting Point of Sulphur.*—Draw out, in the flame of a laboratory burner, a piece of glass tubing so as to make a small thin-walled tube, about two or three inches long and $\frac{1}{16}$-inch in diameter. Into this tube place some finely powdered sulphur. Tie the filled tube on to a thermometer near its bulb, and put the thermometer into a beaker of sulphuric acid which has been placed over a burner. (Be very careful not to upset the acid.) Gradually heat the acid and keep it at a uniform temperature by moving the curved stirring rod (shown in Fig. 145) up and down. Notice when the sulphur melts and at that instant read the thermometer. This reading will be the melting point of the sulphur. The same method may be used to determine the melting point of wax.

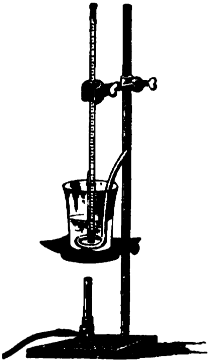

Fig 145.—Determination of melting point.

129. *Melting Point of Ice.*—Pound some pieces of clean ice and thrust a thermometer into the pounded mass. Record the temperature indicated. Put some of the ice into a beaker and pour in some water, stir the mixture and again record the temperature.

Place the beaker on a sand bath and warm gently. Notice the reading of the thermometer *as long as there is any ice unmelted.*

In all these cases the reading of the thermometer is the same, or the temperature of melting ice is constant.

130. *Heat required to Melt One Gram of Ice.*—Weigh about 300 grams of warm water into a beaker, and observe its temperature. Put a few small pieces of ice into the water, stir them round with the thermometer, and, as soon as they have melted, again observe the temperature of the water. Now make another weighing and find out by subtraction the mass of the ice added. From these results calculate in the way shown on p. 195 the number of heat units required to melt one gram of ice.

Melting Points.—When a solid is heated, the first effect of the heating is to make it get larger. But if the heating is continued long enough, when the solid reaches a certain temperature, which differs for different solids, melting begins. The solid changes into a liquid. The temperature at which the melting takes place is called the **melting point**. Thus, when a lump of lead is heated its temperature rises, it gets larger, and as the heating is continued it is converted into a silvery looking liquid. Wax, ice and iron are other examples of solids which melt. But ice, wax, lead and iron differ very widely in the temperature at which they begin to melt, as the following table shows :—

Ice	melts at	. . . . . .	0° C.
Beeswax	„ „	. . . . . .	65° C.
Lead	„ „	. . . . . .	330° C.
Cast iron	„ „	. . . . .	1200° C.

As long as any of the solid remains unmelted the temperature does not rise above the melting point. We can easily satisfy ourselves that this is true in the case of ice. If we pound some pieces of clean ice, and thrust a Centigrade thermometer into the powdered mass, we shall notice that the thermometer records a temperature of 0° C. Or, if we put some of the ice into a beaker and pour in some water, we shall find after we have stirred the ice and water together for a little while, provided we have put enough ice to be sure that it does not all melt, that the thermometer still records a temperature of 0° C. And even if we put the beaker with the ice and water in it over a laboratory burner and warm gently, we still find that, as long as there is any ice unmelted, the thermometer still reads 0° C. It is very evident, then, that the temperature of melting ice is always the same, and remains the same as long as there is any ice unmelted.

Latent Heat.—The experiments which have just been described are of the very greatest importance. You should not leave them until you understand what they mean. When the mixture of ice and water is heated over a laboratory burner, it is certain that heat is being continually absorbed by the mixture. Yet the temperature as recorded by the thermometer gets no higher. The question arises, what becomes of this heat which has no effect upon the temperature of the mixture? What effect does the heat absorbed by the mixture have? We certainly notice that the ice is gradually melted, and if we continue the heating long enough it is all changed into water. And as soon as this has happened every further addition of heat raises the temperature of the water. These considerations lead us to conclude that the heat absorbed by the mixture is all used up in bringing about the change of ice into water. Further, it is found that the change from the solid to the liquid state, not only in the case of ice, but of every other solid, can only be brought about by a similar absorption of heat. This amount of heat which is necessary to change a solid into a liquid is spoken of as **latent heat.** The word latent comes from a Latin word, meaning "lying hidden," and refers to the circumstance that the heat used up in changing a solid to the liquid condition has no effect upon a thermometer.

How the Latent Heat of Water is Measured.—To find out how many units of heat are required to melt a gram of ice, we mix together known masses of warm water and ice, the temperature of both being known, and then record the temperature of the mixture at the instant the last piece of ice disappears. The facts which in this way become known are as follows :—

i. Mass of warm water in grams.
ii. Mass of ice in grams.
iii. Temperature of warm water.
iv. Temperature of the ice.
v. Temperature of the mixture at the instant the ice finally disappears.
vi. Number of degrees through which the temperature of the water falls.

You must now consider what number of heat units have been lost by the water, and what number have been gained by the ice and by the water into which the ice is changed as it melts.

The loss of heat is at once calculated by knowing that a certain number of grams of water have fallen through a given number of degrees of temperature, and if these numbers are multiplied together the result shows the number of units of heat lost by the warm water.

The gain of heat consists of two parts ; first, the number of units of heat necessary to melt a known number of grams of ice, and this number we do not know. Secondly, the number of units of heat required to raise the temperature of the mass of water at 0° C. (formed by melting a known number of grams of ice) up to the temperature of the mixture. This number of units of heat we know by multiplication.

We also know that the total loss of heat and the total gain of heat are equal. Consequently, it should be plain that the difference between the two known results obtained above tells the number of units of heat used up in melting the ice.

Latent Heat of Water.—The number of units of heat which are required to change the state of a gram of ice, converting it from the solid to the liquid condition, without raising its temperature, is called the latent heat of water, or the **latent heat of fusion of ice.** To melt one gram of ice requires 80 heat units. That is to say, as much heat as would raise the temperature of a gram of water through 80° C., or would raise the temperature of 80 grams of water through 1° C., is used up in changing a gram of ice into a gram of water at the same temperature. Similarly, to melt 1 lb. of ice requires as many heat units as are necessary to raise the temperature of a pound of water from 0° C. to 80° C., or as much heat as is wanted to raise the temperature of 80 lbs. of water through one degree Centigrade.

Natural Consequences of Latent Heat of Water.—Just as it is necessary before a pound of ice can be changed into a pound of water to pour into it an amount of heat which would raise the temperature of a pound of water through 80° C., so before a pound of water can be changed into a pound of ice, we must take from it precisely the same amount of heat. This is why it takes so many cold nights to cover a pond with ice, for not until every pound of water at the surface has had this large amount of heat taken from it can it change into ice. For just the same reason, it takes a very long time to completely melt the snow in the roads and the ice on the ponds, even after a thaw has set in.

Heat Absorbed in the Conversion of Water into Steam.

EXPERIMENTAL WORK

131. *Latent Heat of Steam.*—Arrange a flask with the connections shown in Fig. 146. The short length of wider glass tube is a trap to catch condensed steam. Put some water into the flask and boil it. While the water is getting hot, weigh out about 300 grams of water in a beaker or a thin metal vessel, and observe its temperature. After steam has been issuing from the glass tube for a few minutes, place the

beaker A so that the end of the tube is well under the water, and let it stay there until the thermometer records a temperature of about 40° C.

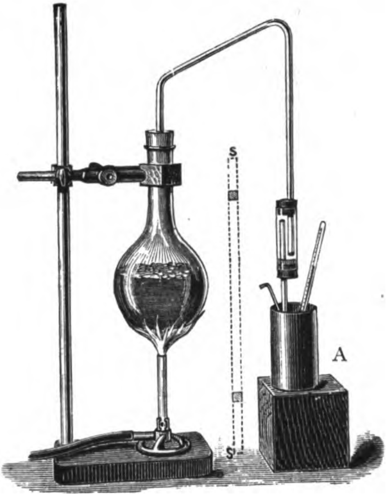

FIG. 146.—Apparatus for determining the heat required to convert water into steam.

Then weigh the water again to find the mass of steam condensed. Enter the observations as follows :—

Mass of water .... gm.
Mass of water + mass of condensed steam.......................gm.
Mass of condensed steam ...... gm.

Temperature of water at beginning ....° C.
,, ,, ,, at end ...° C.
Rise of temperature ....° C.

As before, the changes of temperature can be arranged under two heads :—

GAIN.	LOSS.
. . . . . . gm. of water were raised through . . . . . . ° C. The quantity of heat used equals mass of water × rise of temperature. = ... heat units.	. . . . . . gm. of steam were condensed to water at 100° C. . . . . . . gm. of water at 100° C. fell to . . . . . . ° C., that is, through . . . . ° C., and the quantity of heat thus given up equals mass of condensed steam (water) × fall of temperature. = ... heat units.

You thus see the quantity of heat gained, and how much of the gain was due to condensed steam falling from 100° C. to the final temperature. The remainder shows you the amount of heat given up by a certain mass of steam in condensing into water. Find the amount of heat given up by 1 gm. of steam in condensing to form 1 gm. of water.

Latent Heat of Steam.—You have noticed several times in different experiments that when once water has started to boil, its temperature gets no higher than the boiling point. As long as there is any water left, no matter how much you heat it, its temperature remains the same. After what has been learnt about the latent heat of water, you will have no difficulty in understanding the reason for this. All the heat is absorbed, or used up, in bringing about the change from the liquid state to that of vapour. It requires a great many more heat units to convert one gram of water at a temperature of 100° C. into steam at the same temperature, than it does to change a gram of ice at 0° C. into a gram of water at 0° C. Whereas to bring about the latter change requires an expenditure of 80 heat units, to convert a gram of water at 100° C. into a gram of steam without changing its temperature requires no fewer than 536 heat units. Or the **latent heat of steam**, or as it is sometimes called. the **latent heat of vaporisation of water**, is 536. Expressed in another way, we may say that it requires as much heat as would raise the temperature of 536 lbs. of water through 1° C. to simply bring about the change of one pound of water at 100° C. into one pound of steam at the same temperature. It must also be remembered that a liquid is never changed into a vapour without some absorption of heat. This is true whether the change takes place quietly in evaporation or rapidly as in boiling.

Some Familiar Instances of the Heat absorbed when a Liquid is changed into a Vapour.—If you sprinkle some liquid, such as ether or alcohol, upon your hands and wave them about, you notice the hands get cold. This is because the heat necessary to bring about the change from liquid to vapour is taken from the hand.

A dog cools himself by letting his tongue loll out. This is because the evaporation which takes place from the large surface of tongue exposed causes heat to be taken from the tongue itself, and to consequently cool it. In tropical countries, where the land gets very hot during the day, evaporation takes place so rapidly after sunset that the water becomes sufficiently cooled by the extraction of so much heat to bring about the change from liquid to vapour that it freezes. Again, not only is the dust laid by watering the roads in summer, but the air is pleasantly cooled by the evaporation of the water.

Summary of Results.—We have now learnt the results of heating ice. Beginning with a lump of ice at a temperature of 0° C., we know that it melts and changes into water at 0° C. when we have poured 80 units of heat into every gram of it. Now we must carefully revise the further effects of continuing the process of heating. After all the ice has been changed into water at 0° C., each successive addition of heat has two effects. First, the temperature is raised, and secondly, the size or volume of the water is altered. While, however, the temperature rises regularly, the alterations in size are not regular. As we have found, the size of the water gets smaller and smaller to begin with for every degree increase of temperature. This is continued until the temperature of 4° C. is reached, at which temperature the water has a smaller size than at any other, or it is at its maximum density. From 4° C. onwards, the temperature and volume of the water increase together as it is more and more heated, and this holds true until a temperature of 100° C. is reached, when the water is changed into steam as the water boils. When once the water has commenced to boil the temperature remains at 100° C., or as it is called the *boiling point* of water, as long as any water is left. But if we had a quantity of steam in an enclosed vessel away from water, we could go on raising its temperature above 100° C., and should obtain what is known as *superheated steam.*

Graphic Representation of the Changes of Volume and Temperature accompanying Changes of State of Water.—These changes of volume and temperature are of such importance that we must take every means of making them clear, and it will help the reader to understand and remember them more easily if we represent them graphically. One way of doing this is shown in Fig. 147. The changes in temperature are marked on the right hand of the diagram. The width of the shaded portions of the illustration represents the volume at the various temperatures. Beginning at the bottom of the figure, we are supposed to start with a lump of ice at – 10° C., and to gradually warm it. Until the temperature reaches 0° C. the ice behaves like most other solids, and regularly expands as it is warmed. When the temperature of 0° C. is reached, though the heating goes on steadily, the temperature does not alter. The heat is used up in changing the ice into water, and the volume of the water, as shown by the width of the shaded portion of the figure, is less than that of the ice. When all the ice is changed into water, the further addition of heat causes the increase of temperature up to 4° C., but as the width of the shaded parts shows, the volume gets smaller until this temperature is reached. From 4° C. to 100° C. the diagram shows temperature and volume increasing together. The temperature remains at 100° C. until all the water is changed into steam, and the size of the steam is 1,700 times greater than that of the water at 100° C. from which it was formed. Or, we can use

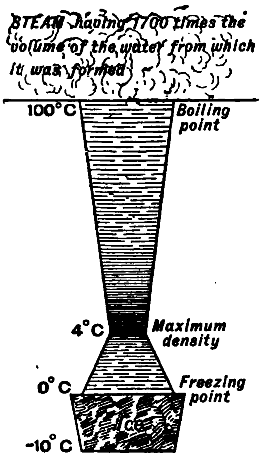
STEAM having 1700 times the volume of the water from which it was formed
100° C
Boiling point
4° C
Maximum density
0° C
Freezing point
Ice
-10° C

FIG. 147.—Changes of volume of water from – 10° C. to 100° C.

squared paper as shown in Fig. 148. The temperatures are represented along the horizontal line, and the volumes by vertical distances above this line. The explanation of Fig. 147 will also make this diagram quite clear.

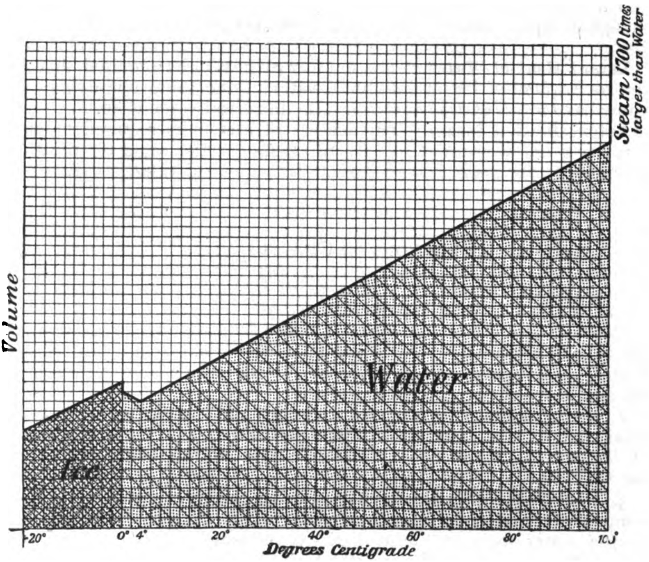

FIG. 148.—Graphic representation of change of volume of water at different temperatures.

CHIEF POINTS OF CHAPTER XIII.

Changes in Volume as Water is Cooled.—Water steadily contracts as it is cooled to 4° C. If the cooling is continued below 4° C., the water begins to expand, and does so until 0° C. is reached.

The density of the water in the same circumstances increases until 4° C. is reached, from which temperature it diminishes as the cooling proceeds; 4° C. is known as the temperature of *maximum density of water.*

In its conversion into ice, water expands very much and with great force.

Melting Points.—The temperature at which a solid melts is called its *melting point*.

Latent Heat.—The amount of heat necessary to change a solid into a liquid at the same temperature, or the amount required to change a liquid into a gas at the same temperature, is called *latent heat*.

Latent Heat of Water.—The number of heat units required to convert one gram of ice at 0° C. into water at the same temperature is known as *the latent heat of water*. Its numerical value is 80.

Latent Heat of Steam.—The number of heat units required to convert one gram of water at 100° C. into steam at the same temperature is known as *the latent heat of steam*. Its numerical value is 536.

QUESTIONS ON CHAPTER XIII.

1. A beaker containing a mixture of ice and water is heated be means of a flame, being kept well stirred all the time.

Describe how the temperature, as shown by a thermometer, of which the bulb is immersed in the contents of the beaker, will vary as the heating is continued, and give reasons for the peculiarities observed in the rate at which the temperature rises.

2. When matter is transformed from the liquid to the gaseous state, what changes take place in its physical properties and the arrangement of its parts? Is the chemical constitution of the body altered by vaporisation?

3. Four ounces of hot lead filings and four ounces of water at the same temperature are poured upon separate slabs of ice. Will the lead or the water melt the most ice? Give reasons for your answer.

4. How would you prove that when ice is melted heat is absorbed without rise of temperature?

5. Define what is understood by the melting point of a solid. Explain how you would proceed to determine this temperature in the case of beeswax.

6. What happens precisely when a liquid boils? What connection is there between the boiling point of a liquid and the pressure of the atmosphere?

7. Give a detailed account of the changes in volume and temperature which are noticed as a piece of ice is continuously heated.

8. What is meant by the latent heat of fusion? Apply your definition to account for the length of time necessary to effect a complete thaw after a season of frost.

9. Describe and explain the means adopted to obtain ice in tropical countries.

10. Why is ice wrapped in flannel in the summer when we want to preserve it?

11. What do you understand by the temperature of maximum density of water? How has this temperature been determined?

12. Explain carefully the changes in volume and density which water undergoes as its temperature is raised from 1° to 99° C.

13. An ounce of water at 0° C. is mixed with ten ounces of water at 70° C. What is the temperature of the mixture?

An ounce of ice is dissolved in ten ounces of water at 70° C., and the temperature of the mixture is found to be something over 56° C. What can be learnt from this experiment?

14. What do we mean by the "boiling point" of a liquid? Explain why good tea cannot be made at the top of a very high mountain.

15. Two test tubes A and B are filled with water. A small piece of ice is allowed to swim in A, and a similar piece of ice is sunk by a weight to the bottom of B. Heat is applied to the closed end of A and to the open end of B. In which test tube may we expect the ice first to melt? and in which may we expect the water first to boil? Give reasons for your answer.

16. How is the reading of a thermometer altered by wrapping a wet rag round the bulb? What will happen if the rag is wetted with (1) ether, (2) oil instead of water? How do you explain the various results?

CHAPTER XIV

TRANSFERENCE OF HEAT

Heat is Transmitted in Three Ways.—Heat is transferred from one place to another in three ways, which will be considered in turn in this chapter.

1. Heat may pass from one particle of a body to the next, travelling from the hotter to the colder parts, and causing no visible motion of the particles of the body. This mode of transference is called **Conduction,** and is the process by which solids are heated.

2. When the heated particles actually move from one part of the body to another, causing it to become warmer throughout, the process is known as **Convection.** Liquids and gases become heated in this way.

3. When the heat passes from one point to another in straight lines with great speed, without heating the medium through which it passes, it is said to be transmitted by **Radiation.** The heat of the sun is transmitted through space in this way.

Conduction

EXPERIMENTAL WORK

132. *Relative Conductivities of Metals.*—(*a*) Obtain wires of copper, iron, brass, German silver and of any other metals available. Let the diameters be the same as nearly as possible, and the lengths about 15–20 cms. Fasten the wires upon a strip of wood as shown in Fig. 149. Support the wood in a horizontal position and heat the wires with a flame where they meet. After a few minutes slowly move a safety match along each wire in succession, commencing at the ends away

from the flame, and notice the points at which the matches will light. Repeat the experiment several times; then take away the flame and measure the distance of these points from the heated ends. Find the average distance for each wire.

The numbers obtained will show you the relative conducting powers of the metals of which the wires are composed. Write down these metals in the order of their ability to conduct heat, beginning with the best conductor, and putting against each name the average distance at which the match was ignited upon it.

(*b*) Twist an iron and a copper wire together at one end. At about four inches from the joint fasten a marble on each with beeswax. Heat the joint in a Bunsen flame. Notice that the marble on the copper is the first to fall. Why?

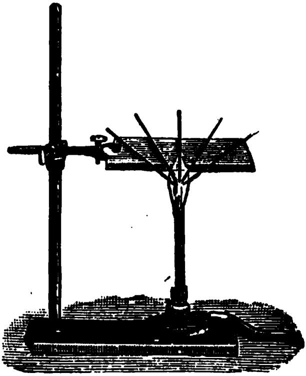

FIG. 149.—Experiment to illustrate the conduction of different metal wires.

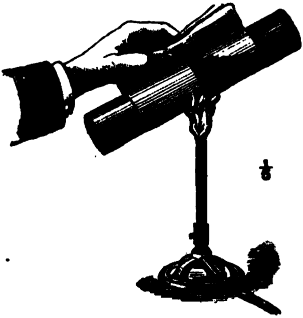

FIG. 150.—Experiment to illustrate the different conductivities of wood and metal for heat.

133. *Conductivities of Metal and Wood.*—Wrap a piece of paper smoothly round a brass tube and hold in the flame of a gas burner. The paper is not scorched. Wrap the paper around a wooden rod of the same size, and heat as before: the paper is scorched, Fig. 150. Brass is a good conductor, wood but a poor one. How does this explain what you have noticed?

134. *Lowering of Temperature by Conduction.*—Make a short coil of stout copper wire ¼-inch internal diameter. Pass it over the wick of a candle without touching the wick. The candle is extinguished owing to the cooling effect of the wire, which conducts away the heat.

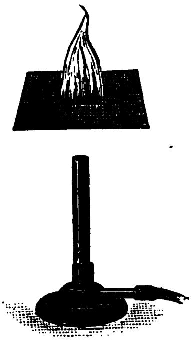

FIG. 151.—To illustrate Expt. 135.

135. *Principle of Safety Lamp.*—Turn on, but do not light, a gas jet. Hold over it a wire gauze, and light the gas above the gauze (Fig. 151). Notice that the flame does not strike through. Why? Vary the experiment by lowering a piece of cold wire gauze upon an ordinary Bunsen flame (Fig. 152). What happens?

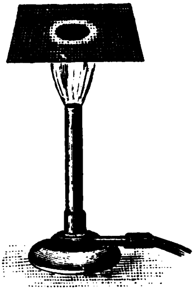

FIG. 152.—To illustrate Expt. 135.

136. *Water is a Bad Conductor of Heat.*—Fill a test-tube three-quarters full with cold water, and having weighted a small piece of ice by winding wire round it, or in some other way, drop it into the test-tube. Hold the test-tube near the bottom where the piece of ice is, and warm the top of the water in a Bunsen flame as shown in Fig. 153. The water at the top can be heated until it boils vigorously and yet the ice is not melted, showing what a bad conductor the water is.

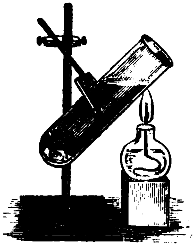

FIG. 153.—To illustrate that water is a bad conductor of heat.

137. *Gases are Bad Conductors of Heat.*—(*a*) Examine the shadow of a red-hot poker. Notice that the heating of the air, as exhibited by its flickering, extends but a very little way downwards, thus showing that air is a bad conductor of heat.

(*b*) Place a little lime in the palm of the hand and bring the point of a hot poker upon it. The air enclosed in the lime does not conduct the heat of the poker, so the hand is not burnt.

Conduction of Heat.—By touching a succession of things in a room, say the marble mantel-piece, the fender, the back of a chair, the hearth-rug, we obtain a succession of sensations; the first two we say are cold, the chair-back not quite so cold, while the rug feels quite warm, and yet they are one and all under the same conditions and there is no reason why they should not be at the same temperature. The explanation of these different sensations is really very simple. In all those cases where the hand *receives heat* we feel the sensation of warmth, while in those where the hand *gives out* heat we say the body is cold or cool. Fig. 154 will enable the student to remember this. Now we see why the fender feels colder than the hearth-rug. The fender takes more heat from the hand than the hearth-rug, and it does so because it is a better *conductor of heat.*

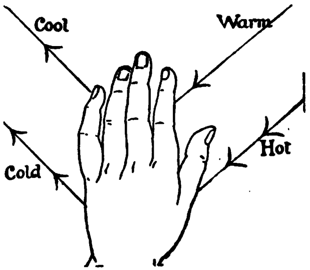

FIG. 154.—Sensation in relation to loss and gain of heat.

We shall do well to consider this expression a little. Put one end of a poker in the fire and hold the other. Soon the poker begins to feel warm, and as time goes on it gets warmer and warmer, until at last you can hold it no longer. Heat has passed from the fire along the poker, or has been *conducted* from the fire by the poker.

The process by which heat passes from one particle of a body to the next is called conduction, and the body along which it passes is known as a conductor.

Good and Bad Conductors of Heat.—Those substances which easily transmit heat in this way are called **good conductors**, while those which offer a considerable amount of resistance to its passage are called **bad conductors.**

The experiments you have performed have shown that some metals conduct heat more easily than others. Because in Expt. 132 (*b*) the marble fell off the copper first, we know the heat travels along copper more readily than along iron. You have probably noticed that a silver spoon soon gets too hot to hold when put into a cup of freshly-made tea, while an ordinary plated spoon never gets inconveniently heated. Similarly, you have proved that wood is a bad conductor of heat compared with copper and other metals. Liquids are, as a rule, bad conductors of heat, though quicksilver, being a metal, is an exception. If liquids were heated only by conduction, water would boil throughout just as quickly when the source of heat was placed in contact with the top layer of liquid as it does when the heating takes place from below.

Gases are even worse conductors of heat than liquids, the everyday methods of taking the conducting power for heat of different substances into account are mostly applications of the very low conductivity for heat which air possesses.

Everyday Uses of Bad Conductors.—To keep ice in the warm days of summer the custom is to wrap it up in flannel and put it into a refrigerator. The flannel, because of its loose texture, encloses a quantity of air, which, being a bad conductor of heat, prevents the passage of heat from the warm outside air to the cold ice inside.

Similarly, ice which has to be conveyed by rail or boat is packed in sawdust.

The refrigerator itself, too, depends upon much the same facts. The common form consists of a double-walled box with a space between the walls. This is either left "empty" as it is called when it is full of air; or, it is filled with some other bad conductor, such as the mineral substance *asbestos*.

If we wish to lift a hot plate we hold it with a folded cloth for the same reason. Cylinders of engines are encased in a packing of some badly conducting material.

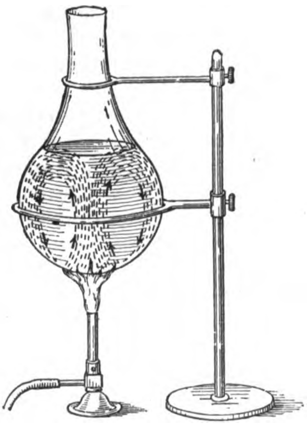

FIG. 155.—Convection currents.

Convection

EXPERIMENTAL WORK

138. *Convection in a Liquid.*—Heat over a small flame a round-bottomed flask full of water, as in Fig. 155. Throw into the water some solid colouring matter, like cochineal, aniline dye, litmus, &c. Notice how the hot and coloured water ascends.

139. *Convection Currents in Gases.*—(*a*) Slightly open the door of your room, and hold a lighted candle (*a*) near the bottom, (*b*) at the middle of the opening, (*c*) near the top. How is the light affected? (Fig. 156.)

(*b*) Place a short piece of candle in a saucer, light it, put a lamp glass over it, and pour sufficient water into the saucer to cover the bottom of the lamp glass (Fig. 157). Watch how the light of the candle is affected, and describe what happens. Next cut a strip of card less than half the height of the lamp glass, and nearly as wide as the internal diameter of the top. Insert the card into the lamp glass so as to divide the upper part into halves. Now light the candle again, and see whether it will burn with the divided chimney over it.

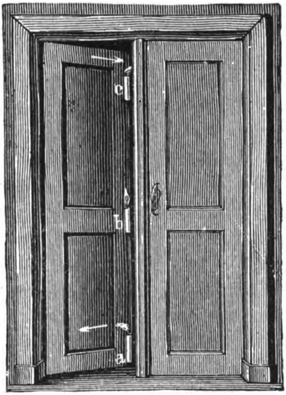

FIG. 156.—To illustrate Experiment 139.

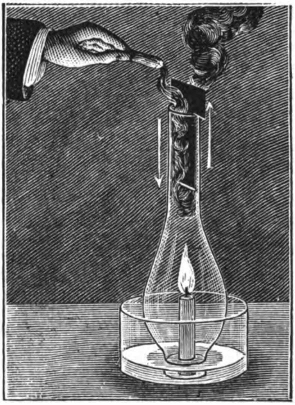

Fig. 157.—How to ventilate.

Test the direction of the currents of air at the top of the chimney by holding a smoking taper or match over it.

Process by which Liquids are Heated.—The process by which water and other liquids are heated may be easily studied by heating water into which some solid colouring matter, like cochineal, aniline dye, litmus, &c., has been thrown in a round-bottomed flask over a small flame, as in Fig. 155. The water nearest the flame gets heated, and consequently expands and gets lighter. It therefore rises, and causes a warm ascending current of coloured water. But something must take the place of this water which rises, and the cold water at the top being heavier than the warm water, sinks to the bottom and occupies the space of the water which has risen. This water in its turn gets heated and rises, and more cold water from the surface sinks. This gives rise to upward currents of heated water and downward currents of cool water, until by-and-by the whole of the water is heated. These currents are known as **convection currents**, and the process of heating in this manner is called **convection**. Eventually the whole of the water gets so hot that the bubbles of vapour which are formed near the source of heat are not condensed again in their upward passage through the liquid, and coming to the surface they escape as steam.

Gases are similarly heated by the process of convection, which may be thus defined:—**Convection is the process by which fluids (liquids and gases) become heated by the actual movement of the particles of the fluid due to difference of density.**

Applications of Heating by Convection.—Heating Buildings by Hot Water.—One of the commonest ways of heating large buildings is by means of hot-water pipes, and the efficacy of this plan is due to the facts we have just learnt. In Fig. 158 we have the condition of things in such a building very simply represented. We will suppose, to begin with, that the boiler B, the pipes *ab*, &c., and the coils C, C′, are nearly full of cold water, and that the fire below the boiler is lighted. Heat passes through the bottom of the boiler by the process of conduction and heats the layer of water near it, which, expanding, rises and passes up the tube *ab* to the top of the building, where it gives out its heat to the rooms. The place of this water which has thus risen is taken by cold water from the other pipe, terminating just past *d*. This in its turn gets warmed and rises, and its place is taken by the water which has become cold by its passage through the pipes in the various rooms. There is thus no difference in this case from what we have seen to be true in the flask of water being heated from below.

Ventilation.—The ventilation of ordinary dwelling rooms is easily possible because of the way in which gases become heated by convection. The air in a room becomes warmed and rendered impure at the same time. Consequently, there is a tendency for the impure air to rise, and if a suitable place near the ceiling is made for it to get out, as well as a place near the floor for the colder, purer air from outside to enter, we shall have a continuous circulation of air set up which will keep the atmosphere of the room pure and sweet.

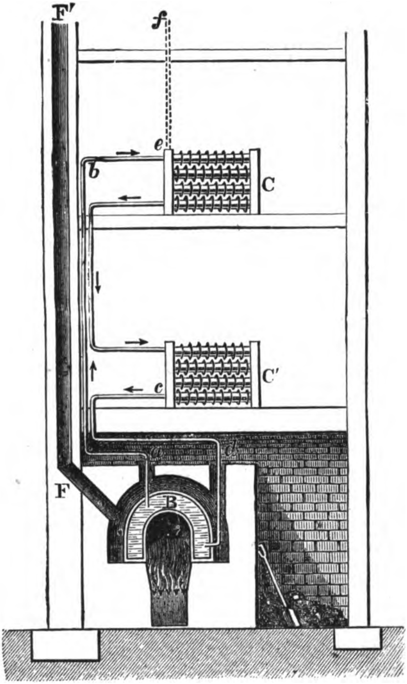

Fig. 158.—Arrangement of pipes for heating a building with hot water.

If the door of a room is opened and a lighted candle is held 1st near the top, 2nd near the bottom, 3rd at the middle of the opening, the light is affected as shown in Fig. 156.

Another experiment is to place a short piece of candle in a saucer, light it, put a lamp glass over it, and pour sufficient water into the saucer to cover the bottom of the lamp glass

(Fig. 157). If we watch we see that the light of the candle is affected and eventually goes out. But if we cut a strip of card less than half the height of the lamp glass, and nearly as wide as the internal diameter of the top, and insert the card into the lamp glass so as to divide the upper part into halves, and we light the candle again, it will be seen to continue to burn with the divided chimney over it. A current of warm air will rise up one side of the strip of card and a current of cooler air flows down the other side to take its place.

Radiation

EXPERIMENTAL WORK.

140. *Heat Transmitted by Radiation.*—(*a*) Place the differential thermometer (Fig. 123) about a foot away from the flame of a laboratory burner so that both its arms and the flame are in one straight line. Notice that the bulb of the thermometer nearer to the flame is hotter than the one more remote. How does the heat of the flame travel to the thermometer?

(*b*) Arrange the bulbs of the thermometer a foot above the flame and observe the nearer bulb is warmed much more than before. The air in this case is heated by convection as well as radiation.

(*c*) When you have an opportunity, focus the rays of the sun upon the back of your hand by means of a reading glass. This can be done by placing the reading glass between the sun and the hand and moving the glass until the brightest image of the sun is obtained. Notice that the heat is very intense and burns you. Notice that the glass itself is not heated to the same extent.

141. *Effect of Surface upon Radiation and Absorption.*—(*a*) Obtain two small bright tin cans or canisters, and fit into each a cork having a hole through which a thermometer will pass. Cover the outside of one of the vessels with lamp-black by holding it over a candle or luminous gas flame, or over burning camphor. Put the same quantity of hot water at the same temperature in each, and then cork up the vessels, each cork having a thermometer through it so that the bulb is well immersed in the water. Observe the temperature of each vessel of water, and if the temperature of one is higher than that of the other, cool the vessel until the temperatures are equal. Then put the vessels in a cool place where there are no draughts, and after 20–30 minutes again read the temperatures.

The blackened vessel will be found to have lost or radiated more heat than the bright one.

(*b*) Similarly equally fill a blackened and a bright vessel with cold water of the same temperature, and hang them for 20–30 minutes at the same distance above an iron plate, supported on a tripod stand and heated by a laboratory burner. At the end of this time observe their temperatures.

The blackened vessel will be found at a higher temperature than the bright one, therefore a lamp-black surface absorbs heat better than a bright metallic surface.

Radiation.—The experiments just described are sufficient to convince you that heat can travel from one place to another in a third way which is neither conduction nor convection. The respects in which radiation differs from the other ways in which heat moves from one place to another are (1) it travels in straight lines and (2) it does not warm the medium through which it travels. Although you may not have thought of the fact that radiation travels in straight lines, you have made use of it when you have screened your face from the heat of the sun or of a fire. When you wish to protect yourself from the glare of the summer sun you seek a shady space because then some object, may be a tree or a house, is in the straight line between you and the sun.

A reading glass is not warmed by the passage through it of the radiations from the sun. Evidently, then while passing through the glass the radiations are not heat. Really, no radiation is heat. It is simply a wave-motion in the medium through which it passes. This medium we shall learn (p. 215) to call "the ether." It is only when certain ether waves are absorbed by material bodies that they give rise to heat. Those ether waves which by absorption give rise to heat are often spoken of as 'radiant heat,' but the name is wrong, as you will understand when you bear in mind that radiations are only wave-motions in the hypothetical medium which is supposed to fill the space between the outer limits of the earth's atmosphere and the sun, and also to exist throughout the mass of all transparent bodies. To speak more accurately, we must say heat travels from one spot to another by radiation when (1) a body in one spot is sufficiently hot to cause wave motions in the ether surrounding it, (2) these are transmitted through the ether to (3) a second body which absorbs the wave-motion and becomes warmed. The subject of radiation is more fully dealt with in subsequent chapters.

CHIEF POINTS OF CHAPTER XIV.

Heat is transmitted in three ways (1) by conduction, (2) by convection, (3) by radiation.

Conduction is the process by which heat passes from one particle of a body to the next.

Gases are worse conductors than liquids, and liquids worse conductors than solids.

Convection is the process by which fluids (liquids and gases) become heated by the actual movement of the particles of the fluid due to difference of density.

Heating buildings by hot water and methods of ventilation are applications of heating by convection.

Radiation differs from conduction and convection in two ways (1) it travels in straight lines, (2) it does not warm the medium through which it travels.

QUESTIONS ON CHAPTER XIV.

1. Why is a vessel of water heated more quickly if heat is applied at the bottom than if it is heated at the top?

Draw a diagram to illustrate the movements of a liquid heated from below.

2. Point out the difference between the conduction and convection of heat.

Describe an experiment showing that water is a bad conductor of heat.

3. Water sometimes spurts from the spout of a kettle standing upon a fire. How do you account for this, and how would you prevent it without taking the kettle off the fire?

4. Explain fully the manner in which liquids become heated. Describe some useful application of the facts.

5. Describe an effective plan for ventilating a dwelling room, and point out the principle upon which it depends.

6. Enumerate the ways in which heat may be transferred from one place to another.

7. How would you compare the conducting powers (as regards heat) of two metals?

8. How does the heat of the sun reach the earth? Explain clearly the form in which it exists before and after reaching the earth.

9. On a cold morning a gardener grasps the iron part of his spade with one hand and the wooden part with the other. Explain why one hand feels colder than the other.

10. If a spoon made of solid silver, and one made of brass and only silver plated, are placed with their bowls in some boiling water, the handle of the silver spoon becomes much hotter than that of the plated one. Why is this?

Describe an experiment by which you would show that your explanation is correct.

11. If a hot lamp-chimney is touched with a cold knife-blade it will often crack. If a tightly-corked bottle full of water is put out of doors on a frosty night it will burst. Explain as fully as you can the reasons for these two results.

12. What is meant by convection?

Illustrate your answer by sketches, taking the case of a vessel filled with water and heated from below and explain why it is that convection is set up.

CHAPTER XV

REFLECTION AND REFRACTION OF RADIATION

Radiation.—In Chapter X. the student has had his attention directed to this subject in considering energy. Radiation was there regarded as a form of energy, and was seen to present itself under several different aspects. Sound was instanced as an example of radiation which, resulting in the first place from a sounding body, is transmitted through the surrounding medium, air, as a vibration of its particles. The vibrating source of sound sets the neighbouring air particles oscillating backwards and forwards, and this one, in its turn, sets its neighbour in motion in the same way all along the line of travel of the sound disturbance. But after the passage of such a disturbance, the air returns to its previous condition and undergoes no permanent change. Such a mode of propagation is spoken of as *wave-motion.*

In this chapter, however, we shall chiefly concern ourselves with those radiations which include light and are conveyed through the other medium which has been already referred to. It is known as *the ether* and pervades all space; it exists as well throughout the mass of all material bodies. These radiations are also propagated by waves, though in a different manner from that in which sound travels in the air. They may be regarded as ether-waves.

Ether-Waves can produce Three Different Effects.—The ether-waves which come to our planet from the sun, and comprise what is inclusively called sunlight, produce different effects. If they fall upon our bodies they may be absorbed, and the energy of the wave-motion become converted into heat, and for this reason the waves which have been absorbed are sometimes spoken of as **Radiant Heat**; if they fall upon the retina of an eye, they may produce a sensation of light, and we then call the waves **Light**; falling upon a photographic plate or upon a green leaf, they may produce certain chemical effects, and are then referred to as **Actinic rays.** The word "rays" means simply kinds of radiation, and hence we may speak of heat rays, light rays, actinic rays. It cannot be too strongly insisted that in their passage through the ether, these ether-waves do not give rise to any of these results; they are simply waves transferring energy by wave-motion.

Radiation travels in Straight Lines

EXPERIMENTAL WORK.

142. *Light Travels in Straight Lines.*—Take three cards and make a small hole in each with a fine needle. Fix the cards on to wooden blocks so that all the holes are at the same height and in a straight line. Place a lighted candle or a lamp in front of the card, and look through the third (Fig. 159). As long as the holes are in a straight line you can see the light from the candle shining through. Move one of the cards aside, and notice that you can no longer see the light. It must be remembered that what is true of light applies equally to all other kinds of radiation.

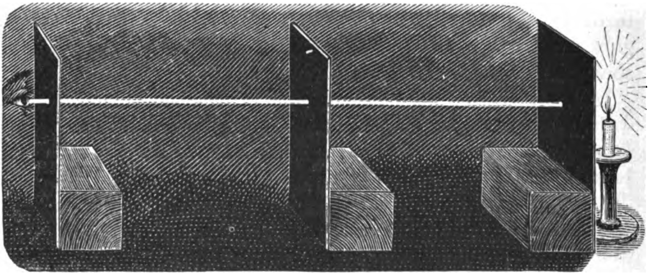

FIG. 159.—To illustrate that light travels in straight lines.

143. *Pin-hole Camera.*—(*a*) Construct a pin-hole camera as follows:—Make two pasteboard tubes, by rolling pasted paper on a wooden cylinder, so that one fits inside the other. For the wider tube previously cover the cylinder with dry paper. Cover one end of the narrower tube with tissue paper and thrust this end into the wider tube. Line with black paper. Place the tube with the pin-hole facing a luminous object, *e.g.*, a candle. Notice that the image of the candle seen upon the tissue paper is upside down. Reason out how this image is formed. Many toy-shops sell cheap pin-hole cameras, which may be used instead of constructing one from tubes.

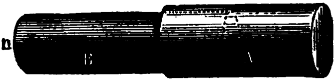

FIG. 160.—A pin-hole camera.

(*b*) Take off the top and knock out the bottom of a coffee canister, and blacken it inside. Then punch a hole in the middle of its length, about $\frac{1}{16}$ inch in diameter. Hold this over a naked candle in an otherwise dark room; a good image of the candle flame will be formed at 6 or 8 inches distant upon a white card, or finely ground glass. (Lewis Wright.)

144. *Overlapping of Images.*—Make several pin-holes near the first one in the pin-hole camera. For every pin-hole there is an image formed on the screen. Make the pin-holes more and more numerous, and nearer together, till the images overlap and become confused. At last diffused light is produced, which is an overlapping of images. This experiment explains why the image becomes blurred, and eventually disappears if the size of the single pin-hole is increased.

Note.—If the teacher can photograph some object well known to the class through a pin-hole, the exhibition of the photograph on the screen is an effective illustration.

Light Travels in Straight Lines.—That light rays travel in straight lines can be at once shown by examining their paths as they pass through a hole in a shutter of a darkened room. Though, as has been learnt, the light-waves are not themselves visible, yet the path of the light becomes apparent because the minute particles of dust in the air are rendered luminous by the vibrations of the ether being absorbed by them. If there were no dust particles in the room the beam of light would not be visible. When the path of a beam is made visible by smoke or dust it is seen to be in a straight line. That light travels in straight lines may, indeed, be inferred from several everyday experiences. We cannot see round a corner; if light travelled in lines that were sometimes bent (we are speaking of a uniform medium), there is no reason why we should not. Or, again, every one knows that it is only necessary to put a small obstacle in the path of the light from a luminous body to completely shut out our view of it. The light from the setting sun, when the sky is cloudy, is often seen to travel in straight lines.

The Images Produced by a Pin-hole are Inverted.—When an object is viewed through a pin-hole camera, it is seen to be upside down upon the screen. Similarly, all images produced by a small aperture are inverted. This inversion is a direct consequence of the fact that light travels in straight lines. That this is really the case can be fully understood by the following simple considerations. Let H, in Fig. 161, be the pin-hole, and AB the candle. Rays are sent out in all directions by every point of the candle, but of all the rays from any point, such as A, only that in the direction AH can pass through the hole and form an image A′. Similarly, the only ray from B which can get through the hole is BH, so an image of B is formed at B′. The same reasoning applies to any part of the candle, hence a complete inverted image is produced.

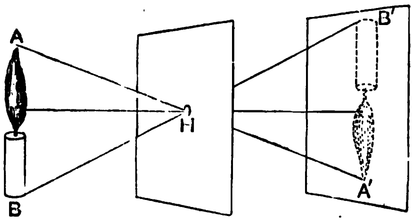

FIG. 161.—To explain why the image of an object produced by a pin-hole is inverted.

Size of Image Produced by a Pin-hole.—That the size of the image depends upon the distance of the screen from the pin-hole is proved practically by varying the distance of the screen from the pin-hole and measuring the length of the image. The greater the distance of the screen the longer the image. The reason for this alteration in the size of the image is a simple one. The farther the rays of light from the top and bottom of the object travel through the pin-hole, since one is travelling upwards and the other downwards, the farther apart they will be the greater the distance they travel. Consequently, the image is longer the more the screen is moved from the pin-hole.

The relation between the sizes of the object and image according to their distances from the aperture is

$$\frac{\text{Length of Object}}{\text{Length of Image}} = \frac{\text{Distance of Object from Aperture}}{\text{Distance of Image from Aperture}}$$

The larger the image the less distinct is it because the small amount of light which can pass through a pin-hole is spread over a greater area.

Illumination Due to Overlapping of Images.—When a pin-hole is made in the tinfoil covering the cap of a lantern from which the condensing lens has been removed, an image of the light in the lantern is formed on the screen, in a darkened room, in precisely the same manner as has been described in the preceding paragraphs. If a second hole be pierced, a second image is obtained. When the number of holes is steadily increased, one at a time, the images, it is observed, start overlapping, at the same time becoming blurred. When the number of images has become considerable no separate image can be distinguished, *diffused* light, as it is called, is produced, and the screen is illuminated in the ordinary way.

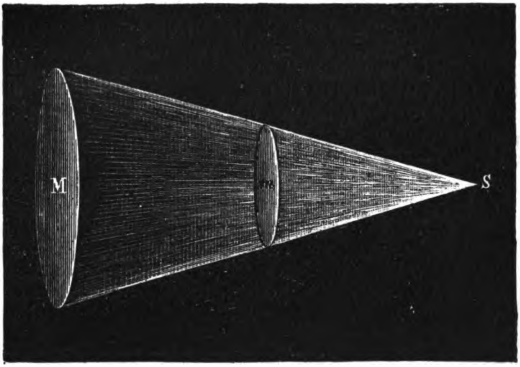

FIG. 162.—Illumination varies inversely as the square of the distance from the source of light.

Intensity of Light.—In proceeding from the source of illumination, light spreads out as indicated in Fig. 162 so that though each ray retains its original intensity the number of rays which illuminate a given area depends upon the distance of that area from the luminous source, S. At twice the distance the rays are spread over four times the area, so their illuminating effect, as at M, is only one-fourth of what it is at *m*. The amount of light received from a luminous source is thus inversely proportional to the square of the distance from the source.

Shadows

EXPERIMENTAL WORK.

145. *Shadows Produced by Small Sources of Light.*—(*a*) Place a stick vertically between the wall and an ordinary fish-tail gas burner, so that the flat flame and the stick are in the same plane. The shadow of the stick on a screen is sharply defined. Turn the flame through a right angle, so that it is now parallel to the screen. The dark shadow is fringed by another less intensely black.

(*b*) Cast a shadow of a sphere on to a screen, using a small source of light, such as a candle-flame. Notice that the shadow cast on the screen is very distinct, circular, and of equal darkness throughout.

146. *Shadows Produced by Large Sources of Light.*—(*a*) Substitute a lamp, with a ground glass globe larger than the sphere, for the candle in the last experiment. Notice that the shadow on the screen is made up of two parts, an inner very dark circular patch called the *umbra*, while concentrically arranged round it is a partially illuminated shadow, forming a ring, called the *penumbra*.

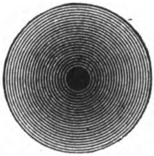

FIG. 163.—Umbra and penumbra.

(*b*) Using the lamp with a large globe as in the last experiment, cast a shadow of a very small sphere. Notice that the shadow comes to a point, as can be shown by moving the screen slowly from the sphere, when the shadow gradually becomes smaller and disappears. This is a *converging* shadow, while those of two previous experiments are *diverging* ones.

Shadow of a Rod.—When the rod in the Experiment 145 (*a*) is illuminated by the edge of the fish-tail burner the shadow of the rod thrown on the screen has sharp edges and it is equally black throughout. This, in common with all the phenomena of shadows you have experimentally studied, is the result of the fact that light travels in straight lines. The light from the edge of a flame is in the place of the illuminated pin-hole, and the explanation offered for the formation of the image by a small aperture applies here also—except that there is no crossing of the rays and no inversion.

Umbra and Penumbra.—When in experimenting with the rod the flame is arranged so as to be parallel with the screen,

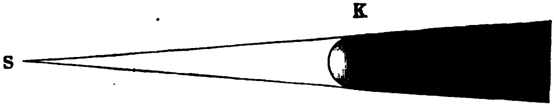

FIG. 164.—Sharp shadow.

the dark distinct shadow—the umbra—is fringed on each side by a less distinct shadow—the penumbra. Similarly, when a sphere is illuminated by a small source of light, such as a candle flame, it casts a clearly defined shadow on the screen, or the umbra only is present (Fig. 164). When, however, the source of light is larger, like the ground glass globe of the lamp, the umbra is surrounded by a partially illuminated concentrically arranged shadow—the penumbra. In Fig. 165 A represents the illuminated globe, B the sphere, and *mn* the screen. By following the course of the rays of light the student will have no difficulty in understanding (1) the formation of umbra and penumbra, (2) how these result from the propagation of light in straight lines.

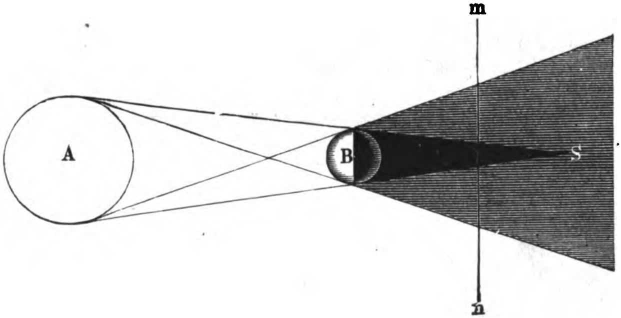

FIG. 165.—To explain how a blurred shadow is produced.

Laws of Reflection

EXPERIMENTAL WORK.

147. *Pin Method of Proving the Laws of Reflection.*—Fix two slabs of wood at right angles as in Fig. 166, AB, CD. Against the upright slab place a piece of glass EF with blackened back so that reflection only takes place from the front. Upon the horizontal slab place a sheet of white paper. Stick a pin *b* in the wood against the glass, and place another pin in the position *a*. Now procure another pin and stick it into the wood at *c* in such a position that *c*, *b*, and the image of *a* are in a straight line. Draw with a finely pointed pencil a line along the edge of the glass *xy*; then take glass and pins away.

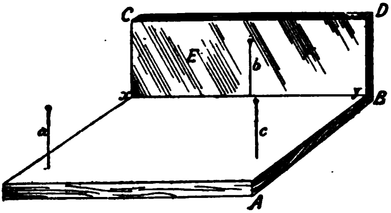

FIG. 166.—Pin method of proving the law of reflection.

The paper will be marked by the pin-holes and the line *xy*. Draw lines through the pin-holes, and at *b*, erect a normal to *xy*, that is, a line perpendicular to *xy*. Measure the angles *abd*, *cbd*, and compare them (Fig. 167). Repeat the experiment two or three times, with the pins in different positions, and so determine that the angle of incidence and the angle of reflection are equal.

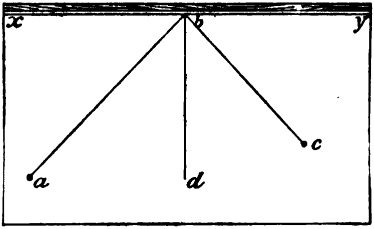

FIG. 167.—Angles of incidence and reflection.

148. *Laws of Reflection illustrated by a Mirror.*—Fasten a little whitened, wooden stick with wax perpendicularly at the centre of a plane looking-glass. Cast upon the mirror, at the foot of the rod, a beam of parallel rays from the lantern, or a sunbeam coming through a hole in a screen. Notice (*a*) that the reflected beam always makes the same angles with the mirror and the stick as the incident beam does, and (*b*) that the incident beam, the stick, and the reflected beam all lie in one plane (Fig. 168).

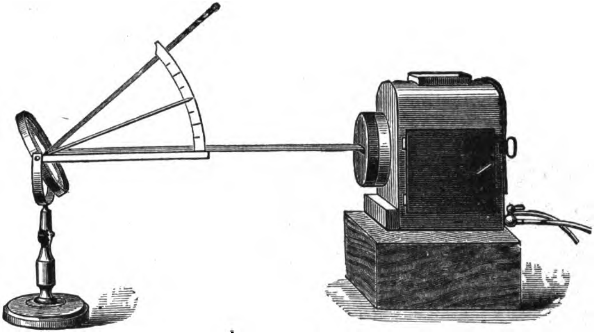

FIG. 168.—To illustrate Experiment 148.

149. *Reflection at two surfaces.*—Place a lighted candle in front of a thick plate-glass mirror as in Fig. 169. Notice that two images can be seen when viewed a little from one side. One is due to reflection at the front surface, and the other is produced by reflection at the silvered back surface.

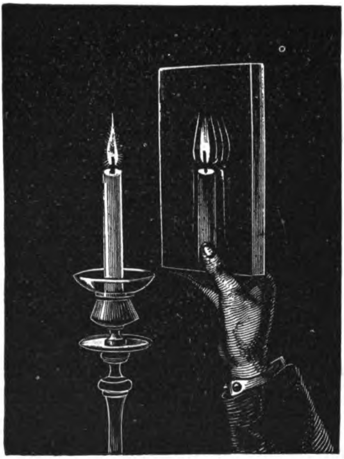

FIG. 169.—Multiple images produced by a thick mirror.

Reflection of Light.—When any wave is said to be *reflected*, it is understood that it comes into contact with the surface of some body, and is thrown back from that surface, and travels in a direction opposed to that in which it was originally moving. This may happen in two ways, either **regularly** or **irregularly**. In the first case it is turned back according to fixed rules, while in the second there is no uniformity about the reflection. The page on which this is printed appears to be white because, owing to the roughness of the paper, of the irregular reflection of the light which falls upon it. Or, if we powder a sheet of glass, the powder seems to be white for a similar reason; there are many surfaces formed from which irregular reflection takes place. The manner in which the rays leave the surface of a body when irregularly reflected can be seen in Fig. 170.

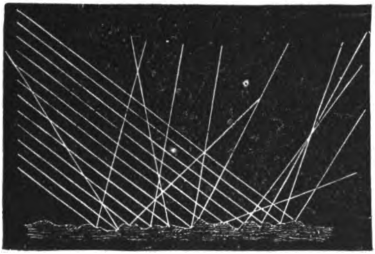

FIG. 170.—Irregular reflection.

Regular Reflection of Light.—Light is regularly reflected from a plane mirror, that is, a flat reflecting surface. Such a mirror can be made from a variety of substances, but the most common is of bright metal or silvered glass. To find the relation between the angle at which a beam strikes a mirror and the angle at which it is reflected, one at least of the experiments described should be performed.

From these observations we learn that the light strikes the mirror at a certain angle and leaves it at the same angle. The angle at which the light or any sort of wave strikes the reflecting surface is called the **angle of incidence**, and the wave an **incident wave**. The angle at which the wave leaves this surface is known as the **angle of reflection**, and the wave as it leaves the **reflected wave**.

Laws of Regular Reflection.—From the experiments and considerations which have now been described we arrive at two laws which must be very carefully remembered :—

1. **The line representing the reflected wave is in the**

same plane with the normal and the line representing the incident wave, and is on the opposite side of the normal from the incident line.

2. **The angle of incidence is equal to the angle of reflection.**

The student must bear in mind that these laws apply equally to all forms of radiation, whether in the ether or in air; *i.e.*, to all ether waves and to all sound waves.

It was also learnt from Expt. 148 that when a wave strikes a reflecting surface *normally*, *i.e.*, having travelled along the normal, it is reflected back upon the same line.

Formation of an Image by a Plane Mirror.—The two rules just enunciated enable the formation of an image by a plane mirror to be easily understood.

Let MM be the plane mirror, and A a bright spot of light like the head of a pin in Expt. 147. First see what happens to the light ray which leaves A and strikes the mirror normally. It is reflected back along the same line and the reflected ray appears to come from a point A′ along A′A. In the case of any other rays, such as AB, the light ray is reflected in such a way that the angle of reflection CBD is equal to the angle of incidence ABC and appears to an eye placed as in Fig. 171 to come along BD from a point A′, where BD produced meets AA′. If we make the same construction for any other ray AB′ it will be reflected and appear to be coming along B′D′, which produced backwards will pass through the same point A′. A′ is therefore the image of A, and it can be easily proved by geometry that A′ is as far behind the mirror as A is in front of it.

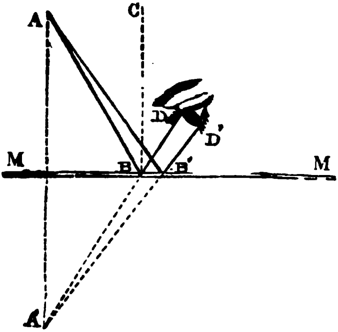

FIG. 171.—The formation of an image by a plane mirror.

These facts apply equally to the formation of the images of *objects*, which can be considered as accumulations of small material particles to which the construction given above for a point may be applied. For instance, the course of rays by means of which an image of a candle may be seen in a plane mirror is shown in Fig. 172.

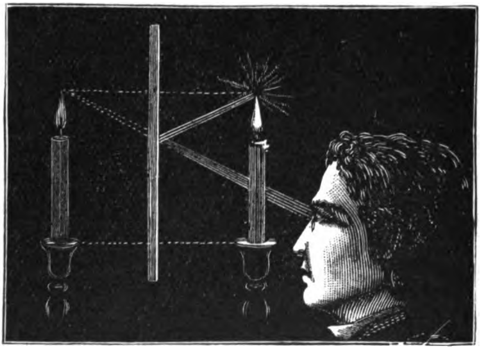

FIG. 172.—Course of rays by which the image of a candle is seen in a plane mirror.

Rotating Mirrors

EXPERIMENTAL WORK.

150. *Principle of the Sextant.*—At one end of a piece of board 1 foot long, by 4 inches wide, fasten by sealing-wax a cork upright; through this pass horizontally a piece of glass tube about 2 inches long and ¼-inch internal diameter. Stretch a vertical thread across the opening of the tube nearest the other end of the board (Fig. 173). Towards the other end of the same side fasten a circular sheet of cardboard divided into degrees, the 0° being nearest to the tube and in the middle of the board. Pivot in the centre of the circle two radial arms, one above the other,

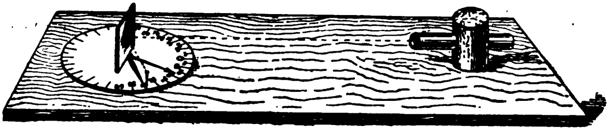

FIG. 173.—Apparatus to illustrate the principle of the sextant.

one carrying at its end a vertical pin, the other a central mark. The second carries a 2-inch square piece of silvered glass in a vertical plane perpendicular to the arm. The pin-bearing arm being placed anywhere, the mirror-bearing arm is turned till the reflection of the pin is seen and coincides with the thread in the tube. Whenever this is the case, the reading of degrees indicated by the pin is always twice as great as where the marked arm is.

When a Mirror rotates, the Angle through which the Image moves is twice the Angle through which the Mirror moves.—This fact, proved practically by the above experiment, is utilised in the *Sextant*, an instrument, used by surveyors and navigators, to measure the angle subtended by two distant objects. Knowing the laws of reflection, the fact can be arrived at very easily by a knowledge of simple geometry. Thus, let MM be a mirror, capable of rotation, when in a vertical position. After a brief interval it will, when rotating, have arrived at a new position M_1M_2. PO is a ray of light which strikes the mirror in its vertical position at right angles.

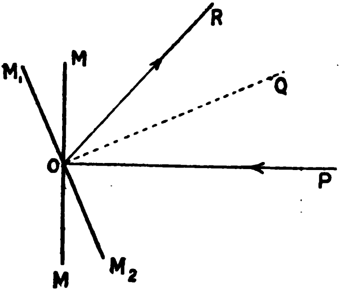

FIG. 174.—Proof that the angle through which the reflected ray moves is double that through which the mirror is turned.

The mirror rotates and the direction of the reflected ray is along OR. It is required to compare the angle POR through which the ray of light moves with the angle MOM_1 through which the mirror moves.

$$\begin{aligned}\text{Angle } POM &= \text{a right angle}\\ \text{Angle } QOM_1 &= \text{a right angle}\\ \therefore \text{Angle } POM &= \text{Angle } QOM_1\end{aligned}$$

$$\left.\begin{array}{r}\text{The angle through which}\\ \text{the mirror moves}\end{array}\right\} = M_1OM = QOM^1 - MOQ$$

$$= POM - MOQ$$

$$= QOP$$

But since angle of incidence = angle of reflection

$$QOP = QOR$$

$$\therefore POR = 2QOP$$

But POR is the angle through which the ray of light moves, and it is twice that through which the mirror moves.

Refraction at Plane Surfaces

EXPERIMENTAL WORK.

151. (*a*) *Refraction by Water.*—Procure a rectangular metal box, such as a cigarette box, and put a wooden or metal scale on the bottom. In a darkened room let sunlight fall slantwise against the edge. The side of the box throws a shadow which reaches, say, to C, which, since light travels in straight lines in the same medium, is a continuation of the rays of sunlight AB. Without disturbing anything, fill the box with water. The shadow no longer reaches to C, but only as far as D. Clearly the light-waves have been bent or *refracted* out of their original course. Notice that NN′ is the normal, and that the light travelling from the comparatively rare air into the comparatively dense water is refracted towards the normal (Fig. 175).

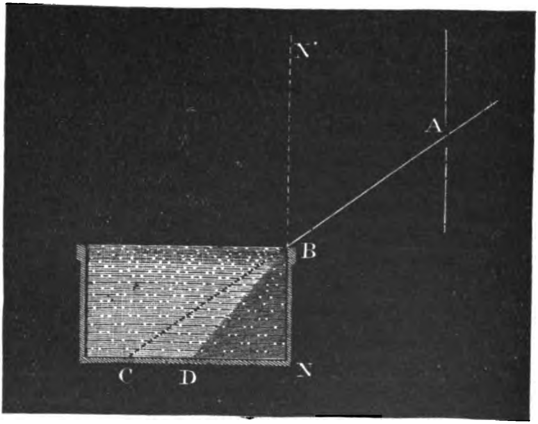

FIG. 175.—Refraction of light.

(*b*) Obtain a medicine bottle with flat faces, and paste over one face a piece of paper having a circular hole cut in it (Fig. 176). On the glass draw a vertical and a horizontal line on the clear space as shown.

Pour water into the bottle until it reaches the level of the horizontal line. Let a narrow beam of light enter the side of the bottle and strike the surface of the water where the two lines cross; it will be found to be bent towards the vertical line in the water.

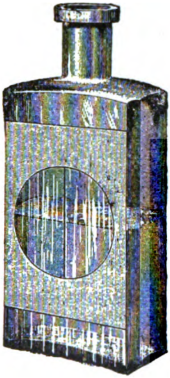

FIG. 176.—Bottle for experiments on refraction.

152. *Pin Method of Proving Laws of Refraction.*—(*a*) Upon a piece of board ABCD

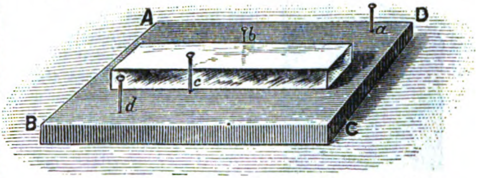

FIG. 177.—Method of determining refraction of light.

(Fig. 177), place a sheet of paper, and upon the paper put a piece of fairly thick glass EF with parallel sides (a thick piece of glass from a box of weights, a paper-weight, or a number of slips of microscope glass will do very well). Rule along the edges of the glass with a finely-pointed pencil. Place two pins, *a*, *b*, as shown in the illustration, and then, *looking through the glass* from the other side, stick in the pins *c*, *d*, so that all four appear in a straight line.

(*b*) Now take away the glass and pins and join the pin-holes on the paper as shown in Fig. 178. Draw the normal *ebf*, and the circle *elfg*. Draw *lm* and *gk* perpendicular to *ebf*. and compare the lengths *lm*, *gk*. Obtain the ratio $\frac{lm}{gk}$ for different positions of the pins; it will be found practically the same in all cases in which the same material is used.

Notice that the direction of the ray *cd*, emerging from the glass, is parallel to that of *ab*.

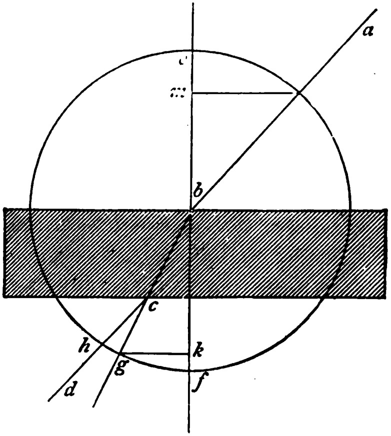

FIG. 178.—Refraction of light passing through glass.

The following experiments will enable the general phenomena of refraction to be well understood.

153. *Phenomena Caused by Refraction.*—(*a*) Place a bright object, say a coin, on the bottom of an empty basin, and arrange your eye so that the object is *just* hidden by the edge of the basin. Get somebody to pour water into the basin. You will now be able to see the coin without any movement of your eye having taken place. Evidently there has been some bending of the direction of the light rays somewhere (Fig. 183).

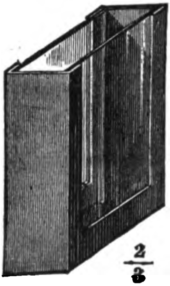

FIG. 179.—Glass cell for use in lantern.

(*b*) Stretch a wire across the opening in the cap of a lantern. Focus the shadow of the wire on the screen. Interpose a strip of glass in front of the wire and tilt the strip. Notice the displacement of part of the shadow.

(*c*) Place a glass cell (Fig. 179) before the lantern and focus it on the screen. Let the surface of the water be visible. Put a lump of ice on the water, and observe the streaky appearance of the illuminated part of the screen. Add syrup, alcohol, and hot water by a pipette. Notice similar effects.

(*d* Pour the vapour of ether out of a bottle, and observe the appearance on the screen Examine the shadows of burning gas, a red-hot poker or of platinum wire through which a current of electricity is passing.

(*e*) Fill a glass cylinder (Fig. 180) with water, and place a coin at the bottom. On looking straight down through the water the coin appears nearer the surface than it really is. Hold another coin near the outside of the cylinder and place it at such a height that the two coins appear at the same level. The amount by which the coin in the water is apparently elevated by refraction can thus be found. The length of the column of water through which the coin is observed, divided by the distance from the top of the water to the outside coin, gives the index of refraction of water.

(*f*) Repeat the experiment with methylated spirit.

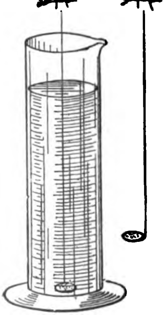

FIG. 180.—To illustrate an effect of refraction.

Refraction of Light—Up to the present the light rays have been supposed to be moving through a medium of a uniform density throughout, such as is the case when it travels through air. When this is so, as we have seen, light travels in straight lines, and, coming in contact with a reflecting medium, is turned back, according to the laws which have been studied. If, however, the light passes from one medium into another of a different density the propagation of the wave is no longer rectilinear, the passage from one medium into the other is accompanied by a bending of its path. This bending is known as **refraction,** and the ray is said to be **refracted.**

Rules of Refraction.—In Fig. 181 the shaded lower part of the diagram represents a denser medium than the unshaded upper portion. The word denser is used here, and in similar connections, to mean optically denser, and must not be confused with what has been said of the density of bodies in Chapter IV. Let RI represent a ray passing from the rarer to the denser medium, or the ray incident on the surface of the denser medium at I. The angle RI makes with the normal at I is the angle of incidence. The ray is bent, as we have learnt; instead of continuing its course in a straight line along IR′ it is refracted and travels in the direction of IS which represents the refracted ray, the angle SIP being the angle of refraction. The angle R′IS which represents the amount the ray has been turned out of its original path is called the *angle of deviation.* With the centre I and any convenient radius describe a circle, and from the points where it cuts the incident and refracted rays draw perpendiculars on to the normal as in the figure. Also drop a perpendicular from the point R′. It is clear from geometry that R′P′ is equal to the perpendicular let fall on to the normal from the point where the incident ray cuts the circle. The ratio between the lengths of R′P′ and SP is constant for the same two media, *e.g.*, air and water, whatever the angle of incidence. This ratio is called the *index of refraction.* Its value for air and water is about $\frac{4}{3}$; for air and glass roughly $\frac{3}{2}$, depending upon the kind of glass.

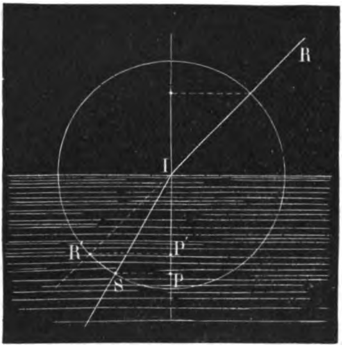

Fig. 181.—To explain the rules of refraction.

The laws of refraction are then :—

1. **The incident ray, the normal, and the refracted ray are all in the same plane. The incident and refracted rays are on opposite sides of the normal.**

2. **If a circle be described about the point of incidence, and perpendiculars be dropped upon the normal from the intersections of this circle with the incident and refracted rays, the ratio of the lengths of these perpendiculars is constant for any two given media.**

Refraction through a Plate with Parallel Sides.—In the case of a ray of light passing completely through a plate of glass, having its sides parallel, the ray is bent towards the normal when entering the glass, and away from the normal when emerging so that its course is as AB, BC, CD, in Fig. 182. The ray is thus displaced laterally, but it emerges in a direction parallel to its original direction. In constructing a diagram for any similar case, it should be borne in mind that when a ray passes from a less dense to a more dense medium, it is bent towards the perpendicular to the separating surface; and when a ray passes from a dense to a rarer medium, it is bent away from the perpendicular to the separating surface.

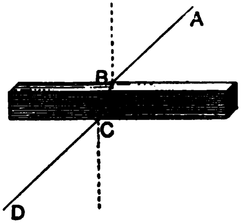

FIG. 182.—Refraction through a glass plate.

Various Effects of Refraction.—Experiment 153 (*a*), with the coin at the bottom of the basin, where being first hidden from view by the edge of the basin, it becomes visible again when water is poured into the basin is easily explained by tracing out the path of the light.

In Fig. 183 let *c* be the position of the coin, in which it is just hidden as far as the eye is concerned by the edge of the empty basin. If the rays from the coin *c* be continued in straight lines these lines will evidently pass above the eye. Now when the water is put in, these rays, which before miss the eye, are refracted in passing out of the water and just enter the eye, making the coin appear to be in the position *c′*. The right side of the vessel, if continued upwards, represents the normal, and

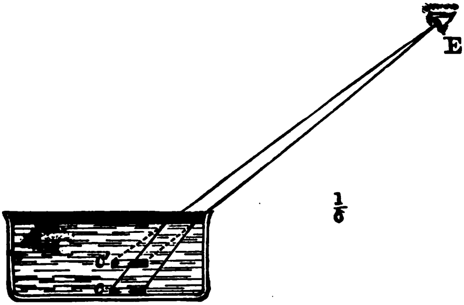

FIG. 183.—Coin experiment to show refraction.

evidently in passing out of water into air the light-waves are bent away from the normal.

The same kind of construction applies to the case when an object is seen obliquely through a thick glass plate, Fig. 184.

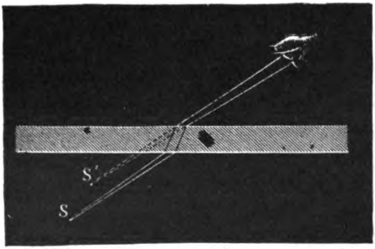

FIG. 184.—Construction to show how refraction causes an object S to appear at S′.

The object is displaced and also made to appear nearer than it really is.

The streaky appearance seen when the light from a lantern is passed through water containing ice is due to the repeated refraction of the light on passing into layers of water of different densities (Expt. 153 (*c*)). This reason, too, explains the similar results obtained when alcohol or syrup are mixed with water.

It is the refraction of light in its passage from one medium into another of different density which explains several very familiar observations. A stick held in anything other than a perpendicular position in water appears to be bent upwards (Fig. 185). If a straight stick is fixed upright in water and looked at from a point a few feet above the end, it will appear shorter than it really is, in the proportion of three to four, so that if a length of four feet was under water, it would appear to be only three feet long. In the same way standing bodies of water always appear shallower than they really are on account of refraction. A pool of clear water only appears ¾ of its actual depth, when viewed vertically.

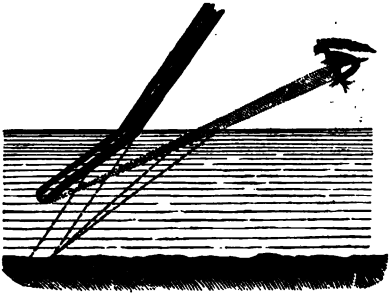

FIG. 185.—To illustrate why a stick placed slantingly in water appears to be bent upwards.

Refraction through a Prism and Lens

EXPERIMENTAL WORK.

154. *Refraction by a Prism.*—Focus on the screen a small circular hole in the cap of the lantern. Introduce a wedge of glass, and observe that the spot is moved towards the base of the wedge. Let the first face of the wedge be oblique to the beam. Put a second wedge with the first, face to face and base to base, so as to form a single wedge of double the angle. Notice the increased displacement of the light spot. Put them edge to base, notice the emergent beam is parallel to the incident.

155. *Pin Method of Tracing Deviation by a Prism.*—Stand a prism upright, that is, upon one of its ends, upon a piece of white paper. Stick two pins into the paper in the positions DE (Fig. 188), place two more E′ D′ on the opposite side of the prism so that the four appear in a straight line when looking through the prism. Draw the outline of the prism *abc*, and then take away the prism and the pins and connect the pinholes as shown in the diagram. It will be found that the ray is bent towards the base of the prism both when it enters and emerges.

156. *Refraction by a Lens.*—Obtain a convex lens, that is, a lens thicker at the middle than at the edges, and notice that if it is held between a luminous object and a small screen, an inverted picture of the object will appear upon the screen.

157. (*a*) *Formation of Images by Lenses.*—Place a convex lens between a lighted candle and a screen, as in Fig. 186, and observe that an inverted image of the candle appears upon the screen.

(*b*) Fix a convex lens of long focal length to form a real image of any object, as *e.g.*, a window, on a card placed at the position *ab* in Fig. 191, in which AB represents the object. Next place on the other side of the card a convex lens of short focal length in such a position that when looking through it, any mark upon the card is clearly seen magnified. If the card is now taken away, the image formed by the other lens is seen magnified. Such an arrangement of lenses forms the ordinary astronomical telescope.

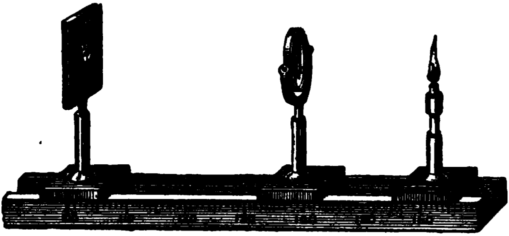

FIG. 186.—Formation of an image by a convex lens.

Refraction through a Prism.—In optics a prism is defined as "a wedge-shaped piece of glass contained between two planes called its faces, which intersect in a line termed the edge of the prism." It may also be defined as a solid having three rectangular sides (Fig. 187).

When such a wedge-shaped piece of glass is interposed in the path of a ray of light from a small hole in the cap of a lantern it is easy to see by watching the image of the hole on a screen that the image moves in a direction towards the base of the prism. This is because the ray is bent by its passage through the prism, so that on its emergence from the glass, it continues in a new path inclined towards the base of the prism. The amount of bending experienced by the ray of light depends upon (1) the angle between the inclined sides of the prism meeting in its edge, or the angle of the prism, as it is called ; (2) the material of which the prism is made and (3) the nature of the incident light.

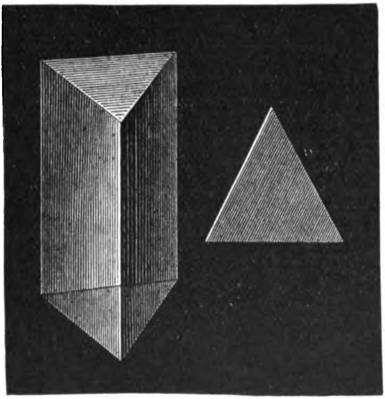

FIG. 187.—General view and cross section of a prism.

If two prisms of the same angle and material are so arranged that the edge of one adjoins the base of the other, the second prism undoes the bending of the first, and the ray as it leaves the combination of prisms continues its path in a direction parallel to the incident ray, though not, of course, in the same straight line with it.

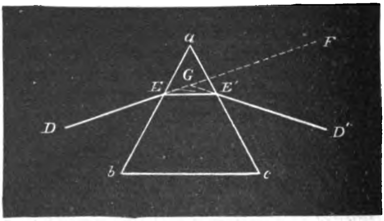

FIG. 188.—Path of a ray of light through a prism.

Path of a Ray of Light through a Prism.—In Fig. 188 let the triangle *abc* represent a section of the prism at right angles to its faces, such as we should see by looking at the end of it. Suppose DE is a ray of light striking the face of *ab* of the prism. The light on entering the prism passes from the air into the glass, or *from a rarer into a denser medium*, and is bent *towards* a line drawn perpendicular to the face of the prism at the point where the ray of light strikes it. It consequently travels along the line EE′ until it reaches the face *ac* of the prism. Here it passes from the glass into the air, *i.e. from a rarer into a denser medium*, and is, in such circumstances, bent *from* the perpendicular, and travels along the line E′D′. In every such passage through a prism it is noticed that the light is always bent or refracted towards the thick part of the prism.

Refraction through a Lens.—Most lenses are of glass with curved surfaces which are portions of spheres. In some lenses one surface is quite plane. All lenses can be divided into two clases—*convex* or *converging*, and *concave* or *diverging*. Converging lenses can be told at once by their power of forming an image of a distant object like the sun, or by that of magnifying. Concave lenses form no image in this way, and, moreover, instead of magnifying they make objects appear smaller when viewed through them.

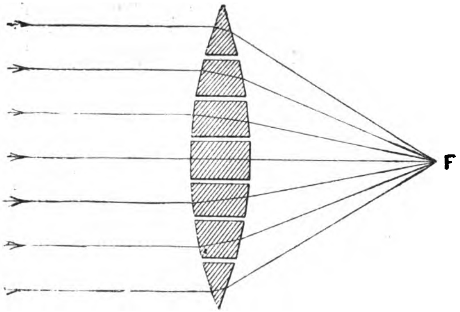

FIG. 189.—Lens built up of parts of prisms.

To understand their action upon the course of rays of light through them it is simplest to regard them as being built up of parts of prisms in contact, as shown in Fig. 189, where a convex lens is built up in this way. A ray of light falling upon any one of these prisms is refracted towards its thicker part, and consequently they all converge towards a point, which, if the incident rays are parallel, is known as the *principal focus* of the lens, as F in Fig. 190. Actually to find the distance of the principal focus away from the centre of the lens, that is, its *focal length*, it is only necessary to form an image of the sun by it on a screen and to measure the distance between the lens and the screen.

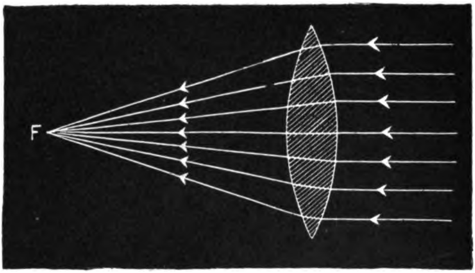

FIG. 190.—To show principal focus of a double convex lens.

The Telescope.—The principle of the refracting astronomical telescope can now be explained. Let O, Fig. 191, be a double convex lens forming an image *a b* of the object AB. This image becomes the object to a second smaller, though in other respects similar, lens, placed near the eye. The second lens forms an enlarged image A′B′ of this the first image *ab*, in the way shown in the figure. A lens placed in the same relation to the smaller one as O is in the figure is called the *object*

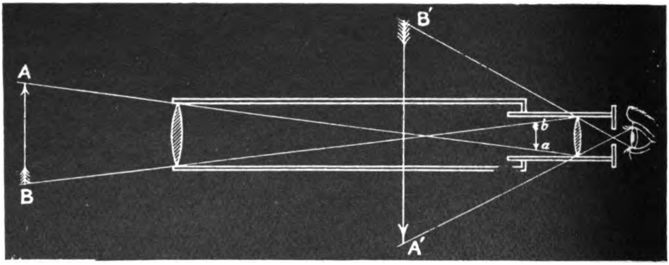

FIG. 191.—Formation of image by telescope.

glass, while the smaller one which magnifies the image formed by the first constitutes the *eye-piece*.

Other forms of Radiation can be similarly Refracted.—The various circumstances which accompany the refraction of light-waves have been found to apply equally to the longer, slower ether-waves which we have called dark heat-waves. If we make a prism or lens of some substance which allows these slower waves to pass through it as easily as glass transmits light-waves, we can obtain similar results by experimenting with them. Such a substance is rock-salt. It has been found by using a delicate instrument known as a thermopile,[1] which reveals the presence of dark heat-waves very readily, in conjunction with a rock-salt prism, that the longer ether-waves are refracted in a manner quite identical with light-waves. So, too, by using a lens of the same material, these heat rays can be brought to a focus.

Sound-waves are also refracted under suitable conditions. By filling a balloon with carbon dioxide we obtain a lens which is able to bring sound-waves in air to a focus beyond the balloon; or, if instead we use a balloon filled with hydrogen, the sound-waves, instead of being made to converge, are caused to diverge. Thus, the balloon of carbon dioxide corresponds to a double convex lens, whereas that filled with hydrogen acts as a double concave lens.

CHIEF POINTS OF CHAPTER XV.

Light, like every kind of radiation, is a form of energy. Hence it is a process of transference of energy by ether-waves. These ether-waves which affect the retina are known as light.

Rectilinear Propagation of Light.—Light travels in straight lines when propagated through any one medium, but often has its direction changed when passing from one medium to another (*see* Refraction).

Consequences of Rectilinear Propagation of Light.—(*a*) The images produced by a pin-hole camera are inverted. (*b*) The size of the image formed by such a camera can be found:—

$$\frac{\text{Length of Object}}{\text{Length of Image}} = \frac{\text{Distance of Object from Aperture}}{\text{Distance of Image from Aperture}}$$

(*c*) Illumination is due to the overlapping of images.

(*d*) The formation of the umbra and penumbra.

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[1] For a description of the Thermopile the student must refer to some book on Electricity.

Reflection.—Light in being reflected from suitable surfaces, obeys the following laws:—

1. The reflected ray lies in the same plane as the incident ray and the normal.

2. The angle of reflection is equal to the angle of incidence.

Rotating Mirrors.—When a mirror rotates, the angle through which the image moves is twice the angle through which the mirror moves.

Refraction of Light.—A ray of light passing from a less dense to a more dense medium is bent towards the perpendicular to the separating surface, and conversely. The laws of refraction can be stated thus:—

1. The incident ray, the normal, and the refracted ray are all in the same plane. The incident and refracted rays are on opposite sides of the normal.

2. If a circle be described about the point of incidence and perpendiculars be dropped upon the normal, from the intersections of this circle with the incident and refracted rays, the ratio of the lengths of these perpendiculars is constant for any two given media.

Refraction by a Prism.—The deviation of a beam of light caused by the action of a prism depends upon (*a*) the angle of the prism, (*b*) its material, (*c*) the thickness of it traversed, (*d*) the length of the ether-waves.

Refraction through a lens.—Most lenses are of glass with curved surfaces which are portions of spheres. They can be divided into convex or converging and concave or diverging lenses. The point to which parallel rays after refraction converge, or appear to diverge, is called the *principal focus*.

QUESTIONS ON CHAPTER XV.

1. A bright bead is placed at the bottom of a basin of water, and a person stands in such a position that he can just see it over the edge of the basin. While he is looking, the water is drawn off. How will this affect his view?

Draw a diagram showing the direction of a ray of light passing from the bead through the water and the air in each case.

2. The sun shines through a crack in the shutter of a darkened room. A person inside the room says that he sees a ray of light entering the room. Put his statement in a more accurate form. What can he really see?

3. A man looks through a thick glass window at a candle above the level of his eye. Draw a diagram to show the passage of a ray of light from the candle to his eye. Explain why the candle is not seen in its true position.

4. A small opaque sphere is placed between a gas burner and a white screen, and when the gas is turned down so that the flame is very small it is found that the shadow cast on the screen is quite sharp, but on turning up the gas so that the flame is large that the edge of the shadow is blurred. Explain the reason for this change, illustrating your answer by means of diagrams.

5. Explain why, if a sheet of paper be placed behind a pin-hole in a thick sheet of cardboard, an image of a brilliantly illuminated object on the other side of the cardboard will be formed on the paper. Why is the image fainter, but more clearly defined, if the pin-hole is very small?

6. A thick layer of transparent liquid floats on the surface of water. Trace the course of a ray of light from an object immersed in the water through the floating liquid to the air.

7. Describe an experiment to show the path of a ray of light which passes obliquely through a thick plate of glass. Illustrate your answer by a sketch in which you indicate clearly the path of the ray in the air before it enters the glass, in the glass, and in the air beyond the glass.

8. What are the laws of reflection at a plane mirror? Describe experiments by which you would prove the truth of the laws you give.

9. A boy wades in a pond which everywhere reaches to about the level of his knees. On account of the water some of the pebbles with which the bottom is covered are invisible and others are not seen in their true places. Explain this, and illustrate your answer by a diagram.

10. Draw a triangle to represent a section of a prism and show how a beam of light is bent by passing through the prism.

11. What experiment could you perform to explain such every-day phenomena as the shallow appearance of a brook, and the apparent bending of a stick which is slantingly plunged into water?

12. A candle is placed close to a looking-glass, and its reflection in the glass is viewed a little from one side. What will be seen? As far as you can, explain the appearances which you describe.

13. An upright post is fixed in the bottom of a pond which is three feet deep; the top of the post is three feet above the water. How will the post appear to an eye about the level of the top of the post and four or five feet away from it? Draw a figure to illustrate your answer.

What will be seen as the eye moves further and further back from the post?

14. Describe a pin-hole camera, and explain, illustrating your answer by a diagram, how the image of a luminous object is formed by it.

What experiment would you perform to show why it is that the image first becomes blurred and then disappears when the size of the hole is gradually increased?

15. Describe in detail, giving a sketch of the apparatus, an experiment to show that when a ray of light passes from water to air it is bent away from the perpendicular, or normal.

16. Three candles are placed quite close together in a row at the centre of a room, and a wooden rod is held in a vertical position at a distance of about a foot from the candles. Explain, giving diagrams, why it is that as the rod is moved in a circle round the candles the shadow cast on the walls is in some positions sharp and in others very ill defined.

CHAPTER XVI

DISPERSION AND THE ANALYSIS OF LIGHT

Refraction is accompanied by Dispersion

EXPERIMENTAL WORK.

158. *Dispersion.*—Place in front of a lamp or lantern a card with a *rather wide* vertical slit. Focus the slit with a lens on a piece of transparent paper or on a white screen. Introduce a glass or water prism into the path of the beam of light. Notice that the image is deviated towards the thick end of the prism as in the experiments on p. 234, also observe the *coloured edges of the image.*

159. *Dispersion a Consequence of Unequal Refraction.*—Repeat the preceding experiment, but instead of a wide slit, use a *very narrow* one, and against it place a piece of red glass. Focus the red image of the slit on a fixed screen by means of a lens, and introduce the glass prism as before—mark where the image is on the screen. Without altering the position of any other parts of the apparatus, substitute a piece of blue glass for the red. Mark where the blue image is formed. Notice that it is farther from the original direction of the beam than the red image was.

Refraction is accompanied by Dispersion.—In all the cases of refraction which have hitherto been considered the phenomena have been described as if all the ether-waves, which are contained in white sunlight, are bent equally, but this is really not so. If the experiments are performed as described, in every case it will be noticed that the image formed by the refracted ray is coloured round its edges. To prevent this complication, and to make the foregoing descriptions quite correct, we must suppose that waves of a given length are used, or, as it is called *monochromatic light*, such, for example, as could be obtained by burning methylated spirit in which common salt is dissolved.

Ether Waves are not all Refracted equally.—What is commonly called "red" light is not so much bent out of its path by a prism as "blue" light. Or, expressing the same fact in another way, red light is less *refrangible* than the blue light. It is found by accurate experiments, which the student will find described in books on light, that the sensation of red upon the retina is due to the absorption of ether-waves which are long and slow compared with those waves which when absorbed by the retina give rise to the sensation of blue. The shortest, most rapid waves are bent most; the slowest, longest waves are bent least. The shortest, most rapid waves which affect the retina give rise to the sensation of violet. Since a prism bends ether-waves of different lengths unequally in this way, it provides a means of separating waves of different lengths from one another. Because they are bent differently the ether-waves are separated or *dispersed* by the prism. This may be expressed by saying that a prism can analyse light composed of waves of different lengths.

The Analysis of Light by a Prism

EXPERIMENTAL WORK.

160. *Formation of a Spectrum.*—(*a*) Using the same arrangement as in the previous experiments, allow sunlight or a parallel beam from a lantern to pass through the narrow slit. Focus the image of the slit on the screen, and as before, interpose the prism. Notice the band of colour. It is called a *spectrum*. Carefully observe, that as in pre-

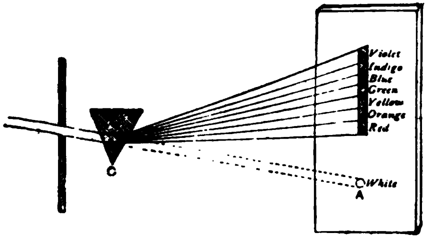

FIG. 192.—The analysis of light by a prism.

vious experiments, the red part has not been so much bent by the prism as the band of the blue. Trace the colours enumerated in Fig. 192 in the spectrum obtained.

(*b*) Place a second prism with its base in the same direction as that of the first. Notice a longer band of colour is obtained, but it is fainter. The amount of dispersion has been increased.

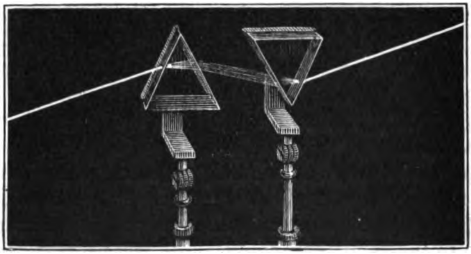

FIG. 193.—Recomposition of light by a second prism.

(*c*) Place the second prism so that its base adjoins the apex of the first prism (Fig. 193). The band of colour disappears.

(*d*) Substitute a hollow glass prism (Fig. 194) filled with carbon bi-sulphide for the solid glass prism used in the preceding experiments. Observe the increased length of the spectrum, owing to the greater dispersive power of the carbon bisulphide.

161. *A Simple Spectroscope.*—Procure a strip of wood about 12 × 1 × ½ inch, and glue a glass prism upright at one end of it. Stick a pin or a needle upright in the other end. Allow the needle to be illuminated by the flame of a spirit lamp into which salt is gradually allowed to fall. An orange-coloured image of the needle is seen. Now illuminate the needle by a candle or gas flame, taking care that the direct light from the candle does not fall upon the face of the prism (Fig. 195). No longer is a single image of the needle seen, but a complete band of colour from red to blue. This is produced by an innumerable multitude of images of the pin close together.

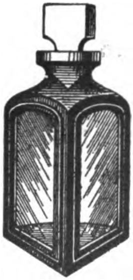

FIG. 194.—Hollow prism for filling with liquid.

Composition of Light.—When sunlight, or as it is called white light, is passed through a prism it is decomposed or dispersed, owing to the different refrangibility of the various kinds of light contained in it. An examination of the band of colour or **spectrum** will show that one colour shades imperceptibly into the next. There is, then, an infinite number of waves of different lengths comprised in the white light from the sun, and each ray is bent to an extent depending on its wave-length.

If the decomposed sunlight, instead of being collected on a screen, be passed through a second prism similarly arranged, it will be seen that the band is longer or the dispersion is greater. The amount of dispersion also depends upon the material of which the prism is made. Glass produces a much greater amount of dispersion than water ; flint-glass possesses twice the dispersive power of crown glass ; carbon bisulphide, again, has even more dispersive power than flint-glass.

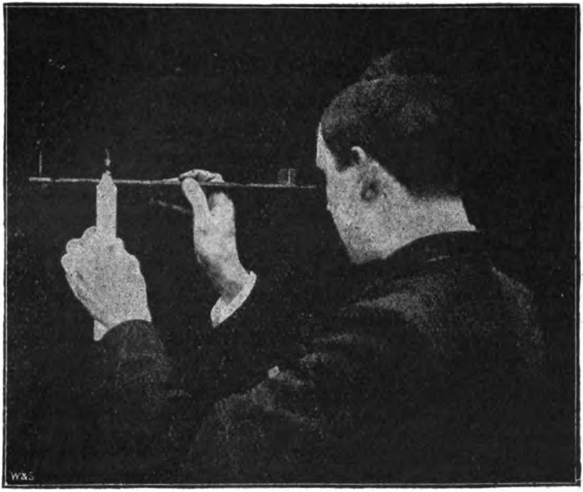

FIG. 195.—To illustrate Experiment 161.

Although a continuous band of colour is observed when sunlight, or limelight, or a gas or candle flame is seen through a prism, this continuous spectrum is not always produced. For when substances such as sodium, strontium, and lithium, or their compounds, are burnt in a non-luminous flame, and observed through a prism, a spectrum consisting of bright lines, which are different for different substances is seen. A prism may thus be used, and is used, to analyse light. The light of incandescent sodium vapour, produced by burning common salt in a flame, when observed through a prism is characterised by a yellow line, and the light emitted by other substances when burning are each distinguished by rays of a particular colour and position in the spectrum.

Recomposition of White Light

EXPERIMENTAL WORK.

162. *Recomposition by a Second Prism.*—Repeat Experiment 160 (*b*) in which a narrow beam of light is passed through two glass prisms of equal angle, and so arranged that the base of one is adjacent with the apex of the other. No spectrum is produced. The second prism undoes the work of the first. It recombines the separate colours and re-forms white light.

163. *Recomposition by a Lens.*—Instead of a second prism, arrange a double convex lens so that the screen passes through its focus. Allow the dispersed light from the first prism to fall upon the lens. Observe that a white image of the slit is formed on the screen.

164. *Recomposition by Colour Disc.*—Upon a round piece of card paint sectors of the different colours contained in the spectrum, arranging the areas of the coloured sectors as nearly as possible in the proportion in which they occur in the spectrum.

Place the card upon a whirling table (Fig. 196) or upon a top, and rotate it rapidly, when it will be found that light from the card gives rise to the sensation of white or grey.

Formation of White Light from its Constituents.—Just as it is possible to analyse white light, splitting it up into its constituent colours or wave-lengths, so, by suitable arrangements, these separated or dispersed colours can be made to recombine, forming white light over again. This building up, or synthesis of white light can be effected in the following ways:—

1. By interposing a second prism with its angle reversed. The dispersion of the first prism is neutralised and the beam of light leaves the second prism in a direction parallel to the beam incident upon the first prism.

2. By causing the dispersed constituents to fall upon a double convex lens. A screen placed at the focus of the lens shows a white image of the slit.

3. By the colour disc.

The Colour Disc.—The explanation of the recombination of the separate colours of the spectrum by means of a rapidly revolving disc, as in Experiment 164, is very simple. It is due to what is called the *persistence of images* on the retina of the eye. Each impression the retina receives lasts for a certain length of time—a fraction of a second. It is not an instantaneous impression only. Think of the common trick of whirling round a stick with a spark on the end—you know this gives rise to the impression of a continuous circle of light. This is because the second impression of the spark is received by the eye before the first impression has died away. Similarly, the impression of one sector, say, a red one, has not disappeared before the next is received, and while these compounded im-

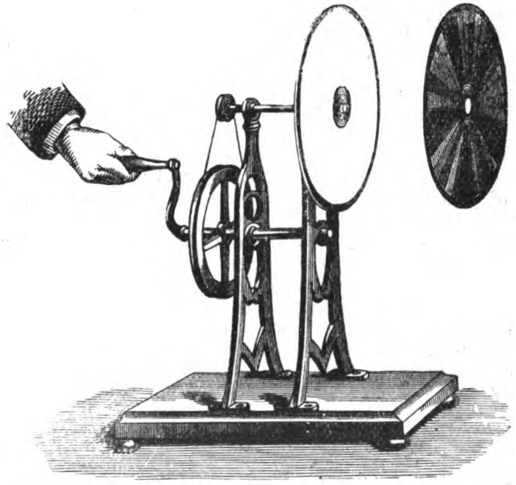

Fig. 196.—The colour disc.

pressions linger a third one comes along. The blurred total of all these rapidly recurring impressions is the greyish white result of whirling the colour disc.

Colour of Bodies

EXPERIMENTAL WORK.

165. *Colour of Transparent Bodies.*—(*a*) Make an Oxford blue liquid by adding ammonia solution to copper sulphate dissolved in water until the precipitate formed is re-dissolved. Place the blue liquid thus made in a glass cell (Fig. 178). Focus the round hole of a lantern cap on the screen. Interpose the filled cell. Notice the pure blue colour. Now interpose red glass either before or behind the cell. Notice that no light can pass now.

(*b*) Use the bi-sulphide prism to produce a long spectrum of a slit on the lantern cap. Pass the filled glass cell from the last experiment through the spectrum, and notice that it is only able to transmit blue light. Repeat the experiment with as many coloured transparent solutions as possible, *e.g.*, a solution of bichromate of potash, and of permanganate of potash. Notice in each case that a particular liquid is only able to transmit light of its own colour.

166. *Colour of Opaque Bodies.*—(*a*) Paint sheets of cardboard with various brilliant colours. Send the light from a lantern in an otherwise dark room upon them and catch the reflected light on white sheets of cardboard. Notice that the colour of the light reflected is the same as that of the card from which it is reflected.

(*b*) Pass through the same spectrum various coloured opaque bodies, *e.g.*, a rod of sealing wax. Notice in this case it is only coloured when passing through the red rays. It appears a dull grey colour in most parts of the spectrum. Observe that green leaves are only coloured when passing through the green part of the spectrum.

Colour of Transparent Bodies.—*The colour of transparent bodies is due to the constituents of white light transmitted by them.* A blue solution through which the light from the cap of a lantern is passed is blue because, of all the colours of the spectrum, it is able to transmit easily only the blue rays; the others, green, yellow, orange, red, etc., are absorbed by the solution. Consequently, if this transmitted blue light falls upon a sheet of red glass it is, in its turn, absorbed; red glass only transmits red light, that is why it is red. So that a combination of the blue solution and a piece of red glass is quite opaque to light—none of the colours of the spectrum can pass. Similarly, pieces of red and blue glass together are, if thick enough, quite opaque. If a strip of coloured glass, or a solution in a narrow test tube, is held between a spectrum and a screen, it appears as a black shadow upon the screen in all parts of the spectrum except in the colour which it is able to transmit. Colourless transparent bodies like glass, water and so on, transmit all the colours of the spectrum with equal facility.

Colour of Opaque Bodies.—*The colour of opaque bodies is due to the constituents of white light which they reflect.* If the light from a lantern in an otherwise dark room be made to fall upon sheets of cardboard which have been painted with various brilliant colours, and the light reflected from the coloured sheets be caught on a white surface, it is at once seen that the colour of the light reflected is the same as that of the card from which it comes.

Coloured opaque bodies when passed through a spectrum only appear coloured when in that part of the spectrum which is the colour they appear to have in white light. A red substance like sealing-wax is red only when there are red rays falling upon it which it can reflect. The sealing-wax absorbs all the other constituents of white light; and hence if it is held in blue light or light of any other colour than red, since all the light rays of this colour are absorbed, no light is reflected and it appears black. A white opaque substance, like a sheet of paper, appears white because it reflects all the constituents of white light equally well. Similarly, if a card painted violet is passed through a spectrum it only appears violet when in the violet rays, and in all other colours it seems black, because it cannot reflect these colours.

General Considerations.—In every case the colour of a body depends on selective absorption or selective transmission. Of the coloured rays of white light one portion is absorbed at the surface of the body. If the unabsorbed portion is transmitted the body is coloured and transparent; if, on the contrary, it is reflected the body is coloured and opaque. In both cases the colour depends upon the constituents of white light which have not been absorbed. Bodies which reflect or transmit all colours in the proportion in which they exist in the spectrum are white; those which reflect or transmit none are black. Between these extreme limits infinite tints exist depending on the less or greater extent to which bodies reflect or transmit some colours and reflect others.

Referring again to the blue solution (p. 248), it absorbs preferably the red and yellow rays of white light, transmits the blue rays almost completely, the green and violet less so, and hence the light seen through it is blue.

Bodies have no colour of their own; the colour of a body changes with the light which falls upon it. It is interesting to remember that this absorption of certain constituents of light necessitates a using up of energy. But since energy cannot be destroyed (p. 153) it is in these cases converted into heat. Theoretically, a blue glass would get hotter than a red one, because the former absorbs all the red rays, and these have a greater heating effect than blue rays.

CHIEF POINTS OF CHAPTER XVI.

Analysis of Light by a Prism.—The points to be remembered in connection with this are :—

1. That if a beam of monochromatic light, that is, light of one wave length, traverses a prism, it is bent out of its original direction, but the amount of bending produced by any particular prism depends upon the colour of the beam used, being greatest for violet light and least for red light.

2. That if light from any source passes through a prism, it is broken up or analysed into its different components, each ray of elementary colour that enters into the composition of the light being bent by a different amount.

3. That if a beam of white light from a slit pass through a prism, it emerges as a coloured strip termed a *spectrum*, in which the colours red, orange, yellow, green, blue, indigo, violet, may be recognised.

White light can, therefore, like a chemical compound, be broken up into simpler elements.

Recomposition of Light—The Colour Disc.—The analysis of white light is noted above; the synthesis, or recomposition, can be effected—

1. By making the coloured band or spectrum, produced when light has passed through one prism, traverse a second prism having its refracting angle reversed.

2. By rotating a disc of cardboard painted in segments of violet, blue, green, yellow, orange, and red.

Colour of Transparent Bodies.—The colour of transparent bodies is due to the constituents of white light *transmitted* by them.

Colour of Opaque Bodies.—The colour of opaque bodies is due to the constituents of white light which they *reflect*.

QUESTIONS ON CHAPTER XVI.

1. Describe and explain the effects observed when cards coloured bright red, green, and blue respectively, are passed from the red to the blue end of the spectrum.

2. A ray of white light is passed through a glass prism; make a sketch showing how the direction of the ray is changed by its passage through the prism and the order of the colours seen when the light falls on a screen.

How would you show that when these colours are re-combined white light is produced?

3. Describe an arrangement by means of which a spectrum may be formed upon a screen.

If the light is made to fall upon a piece of red glass before reaching the screen, how and why will the spectrum be affected? What would the effect have been if blue glass had been used?

4. How can it be proved that—

(*a*) White light is a mixture of many colours?

(*b*) Different colours have different degrees of refrangibility?

5. A room is lighted by one small window, which can be completely covered by a screen of dark red glass, or by one of blue glass, or by both put together. In the room is a stick of red sealing wax, a piece of blue ribbon, and a lily. What colour does each of these things appear when (*a*) the red screen covers the window? (*b*) the blue screen covers the window? (*c*) when both screens cover the window?

6. What is meant by the *Dispersion of Light?* On what fact does it depend?

7. Explain the term *refrangibility* as applied to a ray of light. Are rays of all colours equally refrangible?

8. State how light can be experimentally analysed by a prism.

9. How would you prove that white light is composed of several colours, and how can these colours be combined by experiment to form white light?

10. It is sometimes said that "red glass colours the sunlight red," and that "blue glass colours the sunlight blue." Mention facts or experiments which show that this is not accurate. Put the statement in a more accurate form.

11. An extended spectrum is thrown on a black screen, and a card, on which the letters W, R, V have been painted in white, red and violet respectively on a black ground, is held in succession so as to be illuminated by the different parts of the spectrum. Describe and explain the appearance of the letters in the different parts of the spectrum.

CHAPTER XVII

AIR AND ITS CONSTITUENTS

Mixtures and Compounds

EXPERIMENTAL WORK.

167. *Mixture and Compound.*—Procure some flowers of sulphur or powdered roll-sulphur and some copper powder,[1] in the proportion of four parts by weight of copper to one of sulphur, and shake them together. The result is a mixture of sulphur and copper, the colour of which will be between the yellow of sulphur and the red of copper. If the mixture be examined with a magnifying glass, there will be no difficulty in recognising the particles of sulphur and copper lying side by side. Place a little of the mixture in a test-tube, and pour some carbon bisulphide upon it, and shake well. By this means all the sulphur is dissolved and the copper is left behind. Now heat another portion of the mixture in a dry tube, and carefully notice what happens. First the sulphur melts, and, as the copper gets hot, it suddenly becomes very bright. Allow the tube to cool, and break it to examine the contents. It is neither yellow, the colour of sulphur, nor red, the colour of copper, but almost black. An examination with the magnifying glass reveals no particles of sulphur and no copper filings. No part of the mass will dissolve in carbon bisulphide.

168. *Gunpowder is a Mixture.*—Procure enough gunpowder to cover a crown; put it in a small flask, and well cover it with water. Heat the flask gently for some minutes over wire gauze placed above a burner, and then filter what remains in it. Collect the filtered liquid in an evaporating basin and evaporate it to dryness, when a white substance will be left, which is nitre. Scrape the black residue off the filter-paper and shake it up with carbon bisulphide. Filter this solution through a new paper, and again collect the liquid in a basin. Leave the basin exposed for a little time to the air, and the liquid, which is very volatile, will disappear, leaving the brimstone behind in the form of beautiful crystals. The charcoal which is left on the paper should be dried, and a part of it burnt to show its real nature.

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[1] The copper powder is easily prepared by digesting granulated zinc in a solution of copper sulphate.

Physical and Chemical Changes.—Matter is subject to two kinds of change. Hitherto we have only been concerned with those which influence the properties of matter, leaving its composition unaltered. It has been seen that a body, such as a piece of iron, may gradually increase in temperature, changing from cold iron to hot, and, becoming hotter and hotter, may change in colour, passing from a dull gray to red, and from red to almost white, eventually becoming incandescent and emitting light rays. But if left to itself the iron will begin to cool, passing through the same changes in the reverse order until it reassumes precisely the former condition. Or, again, we might take a piece of soft iron, and, having wound silk-covered copper wire round it several times, pass an electric current through the wire. It would be found, on examining the iron, that new properties had been imparted to it, that it was now able to pick up other pieces of iron, or had become magnetised. If the electric current be discontinued, the new power, too, disappears. Such changes as these, where the substance or composition of the body remains unchanged, are known as *physical changes.*

On the other hand, if a piece of iron be left exposed to damp air for some hours it becomes covered with a reddish-brown powder, which the most superficial examination will show is a different substance from the iron with which we started. There is a very large number of changes of the same kind as this continually taking place around us. When gunpowder explodes, we have an abundance of smoke formed and a black residue left behind, and it is easy to see that the smoke and deposit are quite unlike the gunpowder before the flash. Such changes as these are called *chemical changes.* It is with changes of this second kind that Chemistry is concerned, and we may define this science thus: *Chemistry is that branch of knowledge which deals with chemical changes; those, namely, which result in the formation of new substances with new properties.*

Chemical Elements.—The result of a large number of experiments made from time to time by different chemists, has been to show that there are upwards of seventy different forms of matter which can by no known methods be broken up into anything simpler. By this is meant that if any one of these, such as iron or silver, be selected and treated in any way with which chemists are familiar—for example, if it were subjected to a very high temperature—we should find it impossible to get anything having properties different from what we know to be those of iron or silver, as the case may be. Bodies of this simple kind are called *elements.*

But it must be carefully borne in mind that, as the methods which chemists adopt become more and more refined, it is quite likely that some of these may be found to be wrongly regarded as elements. Up to the time of Davy (1807) the substances soda, potash, and lime were regarded as elements. He found, however, that they could be split up into simpler constituents. From soda he obtained a soft metal, sodium, and two gases, oxygen and hydrogen, and from that time, of course, soda could not be regarded as an element. Similarly, if at any future time it should be found that any of the forms of matter which we call elements can be split up into simpler bodies with different properties, the element which is thus decomposed will have to be struck off the list. Of all the elements known to chemists, only six exist in the gaseous state, under ordinary conditions of temperature and pressure. These are chlorine, fluorine, hydrogen, nitrogen, oxygen, and argon. Two of them, bromine and mercury, are liquids. The rest are solids, and some of the commonest are given in the table.

SOME OF THE COMMONEST ELEMENTS

Gases

Chlorine
Fluorine
Hydrogen
Nitrogen
Oxygen
Argon

Liquids

Bromine
MERCURY

Solids

ALUMINIUM
ANTIMONY
Arsenic
BARIUM
BISMUTH
CALCIUM
Carbon
COPPER
GOLD
Iodine
IRON
LEAD
MAGNESIUM
Phosphorus
POTASSIUM
Silicon
SILVER
SODIUM
Sulphur
TIN
ZINC

Metals and Non-Metals.—A good many of the elements are possessed of certain distinctive characters in which they resemble one another. They have a bright lustre, a high specific gravity (*see* p. 55), are good conductors of heat and electricity and are known to chemists as *metals*. There is no difficulty in deciding in a large number of instances that the element possesses the characters of a metal, and the student will immediately think of gold, silver, copper, iron, &c. Other elements, however, are quite as plainly not of this class; they have no lustre. they are not heavy, nor do they conduct heat and electricity well. These are spoken of as *non-metals*, and phosphorus, sulphur, and carbon will serve as good instances. But the line between the two classes is not a hard and fast one, for one or two of the elements possess some of the properties which distinguish a metal, and yet for other reasons, which the student will understand better later, are not classed with the metals, but with the non-metals. Arsenic may be cited as an instance of an element which possesses properties common to both classes. In the list of elements given in the preceding paragraph the metals are printed in capitals.

Mixtures and Compounds.—The differences between a mixture and a compound will be most easily understood by carefully performing the experiment described above with flowers of sulphur and copper powder. By merely mixing these things together no change in their properties is brought about. By suitable mechanical means they are easily separated. But if the mixture is heated strongly, a profound and permanent change ensues.

What is this great change which has resulted from heating the two elements together? Clearly, that it has resulted in the formation of a new substance with properties of its own. Such a change as this is known as a *chemical change*, and is said to be the result of *chemical action*. The new substance formed from the copper and the sulphur is called a *chemical compound*, and in this particular case there are two elements held together by a force which is known as *chemical attraction*. We are now in a position to enumerate the peculiarities and distinguishing characteristics of mixtures and compounds.

Mixture.—*In a mixture the components exist side by side, and can be separated by suitable mechanical methods. The components* *are not held together by chemical attraction, that is, they are not chemically combined. The ingredients can be present in any proportion, and the properties of the mixture are intermediate between those of the constituents.*

Compound.—*A chemical compound is a substance which can be split up into two or more elements. Its constituents are held together by chemical attraction, and cannot be separated by any ordinary mechanical means. It always contains definite weights of the elements composing it, and its properties differ entirely from those of its constituents.*

Familiar Examples of Mixtures and Compounds.—It will not be difficult to find many examples of mixtures which are familiar to every one. Gunpowder, for instance, is a mixture of three things—nitre, brimstone, and charcoal. They are, however, so thoroughly mixed that there is more difficulty in separating the ingredients than is experienced in the case of a mixture of flowers of sulphur and copper powder. The nitre can be separated from the brimstone and charcoal by shaking the gunpowder up with water. After filtering off the water, the brimstone can be obtained free from charcoal by shaking the residue, after treatment with water, with carbon bisulphide. The sulphur is dissolved and the carbon left.

This shows us that the constituents of the gunpowder are not held together chemically but exist side by side. In a similar way the student will have no difficulty in understanding that the amounts of the nitre and other things can to some extent be varied, and that in the other particulars the gunpowder fulfils the conditions of the definition of a mixture. Another familiar mixture is found in the air we breathe. This is made up of nitrogen and oxygen mixed in the proportion of four pints of the former to one of the latter. The reasons for considering the air to be a mixture will be better understood a little later.

From these examples it will be seen that mixtures can be made up of either elements or compounds.

The simplest chemical compounds contain two elements only and are called *binary compounds*, such as water, lime, common salt. Many others contain more than two elements, and chalk and clay can be mentioned as instances. As we proceed, the student will become familiar with many other instances of chemical compounds of varying degrees of complexity, from the binary compound to those containing a large number of elements.

The Air.

EXPERIMENTAL WORK.

169. *Iron in Rusting Gains in Mass.*—Weigh carefully a watch glass with some iron filings or tacks, add a few drops of water (since we know that iron rusts best in the damp) and allow it to stand. At the end of a few days warm gently to drive off the water, and when *quite dry* again weigh, and note carefully the mass. Has the iron gained or lost?

170. *Iron in Rusting Abstracts one Constituent of Air.*—(*a*) Place some iron filings in a muslin bag and tie the bag to a piece of glass rod. Moisten well (better dip in a solution of sal ammoniac) and place it in a bottle of air inverted over water (Fig. 197). Examine after a few days. It will be seen that the water has risen in the glass, showing that some part of the atmosphere has been abstracted by the iron in rusting.

(*b*) Tightly place your hand on a card under the mouth of the jar so as to allow no water to escape, set upright and place a burning taper into the jar. Note what happens, but do not throw away the water.

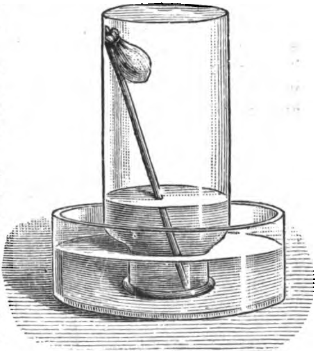

FIG. 197.—Action of iron filings on air.

171. *Volume of the part of the air abstracted.*—Next measure in a graduated vessel the quantity of water in the bottle. This is equal to the quantity of gas which has been used by the iron. Also measure the quantity of water the bottle holds. This is the quantity of air it originally held.

172. *Another Way of Removing the Active Part.*—Place a roll of copper gauze or some copper turnings in a hard glass tube provided with a bored cork at each end as shown in Fig. 198. Find the mass of the tube and the copper. Connect one end of the tube with an aspirator so that air may be drawn through the tube. Heat the copper to redness and cause air to pass over it by starting the flow of water from the aspirator. Notice that the copper turns black owing to its

combination with the active part. Allow the tube to cool and by weighing redetermine the mass of the tube and its contents. The mass has increased.

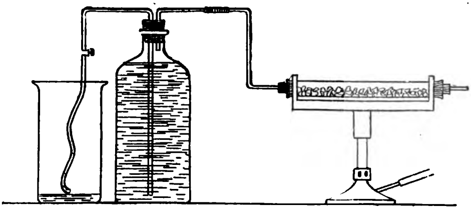

FIG. 198.—Air passed over heated copper loses its active constituent.

173. *Gain of Mass during Burning.*—Weigh a crucible and lid and a piece of magnesium, which, folded lightly, is placed in the crucible. Heat strongly in a burner, taking care to let no fumes escape (Fig. 199). To do this, keep on the lid, and only raise a little when the flame is removed. The magnesium is seen to burn brightly in places; but, if care is taken, no fumes are lost. When finished, the whole mass should be in the form of a white powder. Allow to cool, and weigh the crucible with the lid and powder. Subtract the mass of the crucible and lid to find the mass of the powder. It will almost certainly be found to be *more*, and, if the experiment is carefully done, it will be found that the magnesium has gained about 66·5 per cent.

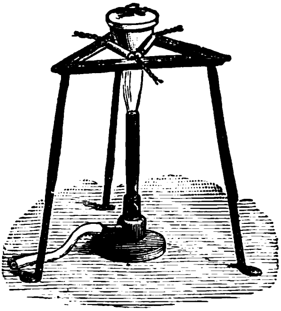

FIG. 199.—To illustrate Experiment 173.

Chemical Action.—In the study of Chemistry it is advisable to start with common and well-known substances, and to examine these as far as possible. The knowledge so obtained is then of service in the further study of other and less common substances.

Chemical Examination of Air.—First, therefore, from its importance and its universal presence, we shall investigate the atmosphere. We know it to be a gas possessing weight and capable of exerting pressure (p. 59). We have now to study its chemical properties. What is it composed of? How does it behave towards other substances? To answer these questions it will be necessary to study carefully the changes which different substances undergo when exposed to the influence of the atmosphere, selecting at first those changes which appear simplest. Of these, the rusting of metals—say, iron—may be chosen. The first problem to be solved is, what is this rusting? Does the iron lose, or give up, anything? Or, on the contrary, does it gain anything? To answer these questions it is only necessary to weigh carefully a watch glass with some iron filings or tacks and allow the iron to rust in the air, which will take a few days; on warming the rusty mass until quite dry and weighing again, it will be found, if care has been taken, that the iron has increased in mass, and the experiment has furnished the necessary answer, so that we may write:—

Iron gains in mass during rusting.

Now we must ask--Did the gain come from the water we added, or from the atmosphere? To answer this question it will be necessary to allow the iron to rust in a closed space, so that if anything is taken from the air we can notice it.

The rusting of the iron is allowed to take place in the apparatus shown in Fig. 197. The iron filings are enclosed in a muslin bag which is placed in a bottle of air inverted over water. On examining after a few days the water will be seen to have risen in the bottle, showing that some part of the atmosphere has been abstracted by the iron in rusting, and if the gas left behind be examined as described in Experiment 170 (*b*), it is easily seen that a lighted taper is put out by it.

The taper being extinguished proves to us that the gas left in the jar differs from air in the respect that it does not allow substances to burn in it. Hence the material taken away from the air by the iron, which with the iron formed rust, is that part of the air which is concerned in burning, and we may state :—

Iron in rusting gains in mass, taking some material from the air, and this material is the part of the air concerned in burning.

If, now, the amount of water in the bottle, after inverting it, as above explained, be measured by means of a graduated jar and the amount necessary to fill the bottle completely be similarly determined, it is found that one-fifth of the air in the bottle is abstracted by the iron in rusting.

Part of the Air can be removed by Heated Copper. If air be passed over red-hot copper, the copper changes in colour and gradually increases in mass. If the remaining part of the air is examined by plunging a burning taper into it, the flame is extinguished. There is no difference between the condition of things in this case and in the rusting of iron. All substances increase in mass when burnt, that is, the products of combustion weigh more than the original substances.

Nitrogen.

EXPERIMENTAL WORK.

174. *Preparation of Nitrogen.*—(*a*) Put a piece of dry phosphorus in a test-tube, cork the tube, and warm. Note that the phosphorus ignites and forms white fumes. When cool again take out the cork under water. Note that the water rises in the tube. Put back the cork and shake up; test the remaining gas; it extinguishes a burning taper, and produces no action if passed into lime water. Test the water with a blue litmus paper; it is acid. Measure the volume of the water; it is one-fifth that of the volume of the closed tube.

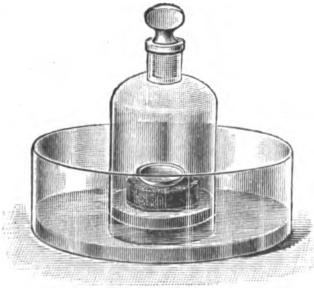

FIG. 200.—Preparation of nitrogen from air.

(*b*) Cut a slit in a large cork so that the handle at the top of a crucible lid will fit into it. Place the lid upon the cork, and float the cork upon the water contained in the trough. Carefully cut off a piece of phosphorus as large as a good-sized pea, dry it, and place the lump upon the floating lid. The cutting should be done under water. Ignite the phosphorus and slowly place over it a jar or a bottle without a bottom and fitted with a cork in its neck. (Fig. 200.) The bottle should have been divided as nearly as possible into five parts by pieces of paper gummed outside. Let the bottom of the bottle either rest on the shelf of the trough or on something suitable placed on the bottom. Allow the apparatus to remain for a few minutes, when the white fumes will have disappeared, and the water will be seen to have risen up to the level of the first division so as to fill one-fifth of the jar.

175. *Properties of Nitrogen.*—Prepare samples of nitrogen, and show (1) that it extinguishes a lighted candle; (2) it will not turn lime-water milky when shaken up with it.

176. *Mixture of Air and Oxygen.*—Mix four volumes of nitrogen with one volume of oxygen (prepared as in Experiment 177 *c*); show that there is no contraction or other manifest change, and that a candle burns in the mixture as in common air.

Chemical Composition of Air.—It has been found by repeating Experiment 174 (*b*) with different bottles at different times, and with different quantities of air, that the ratio of the volumes of the chief constituent gases in air is always roughly 1 : 5, and is independent of the size of the bottle, &c. Hence it is clear that this gives us the proportion of the *active part* of the air, and we may sum up the result of the experiments as follows.

Air contains 80 per cent. *inactive part;* it is called **Nitrogen,** which as has been seen, does not allow things to burn in it, so that the remaining 20 per cent. must be the part concerned in burning, and which we have called the *active part*; its chemical name is **Oxygen.**

Properties of Nitrogen.—This gas nitrogen is an example of a very inert element, since it can only with difficulty be made to combine with any other element. It does not burn, nor will it allow other substances to burn in it; or, as usually expressed, *it does not support combustion.* It will not turn lime-water milky. A mouse dies if put into the gas. It can be made to unite with a few metals, as magnesium or lithium. If either of these be heated with nitrogen the gas is absorbed and a compound of magnesium and nitrogen called magnesium nitride, or a compound of lithium and nitrogen called lithium nitride, is obtained.

If the negative nature of the properties of nitrogen is borne in mind, and if we think of this side by side with the very active powers of oxygen, we shall understand that its presence in the air serves the purpose of diluting the oxygen, weakening its powers, and making combustion much less intense.

If the nitrogen obtained in Experiment 174 (*b*) be heated with either magnesium or lithium it is found that about 1 per cent. of it remains unabsorbed. This residue is another substance present in the atmosphere to the extent indicated, and called **Argon**. Argon is also very inert, more so even than nitrogen. Owing to this, even until the year 1894, its presence in the air had been completely overlooked, although, nearly a century before, the eminent chemist Cavendish had unknowingly obtained some, regarding it as an impurity which he had overlooked—an example of the importance of giving attention to the minutest details in scientific investigations.

Preparation of Oxygen.

EXPERIMENTAL WORK.

177. *Preparation of Oxygen.*—(*a*) Place some mercury rust (known as red oxide of mercury) in a tube of hard glass closed at one end, and heat strongly. Notice the darkening of the powder, also the dark deposit which collects round the inside of the tube above the powder.

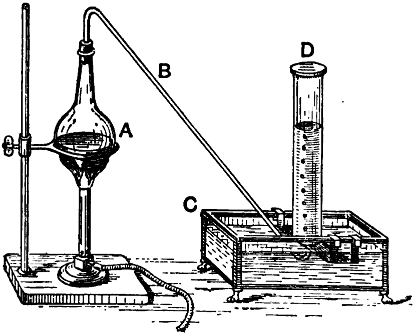

FIG. 201.—Preparation of oxygen.

Place into the tube a splinter of wood which has been just extinguished and is still glowing. Note that it glows more brightly, or even bursts into flame. Allow the tube to cool, and notice that the powder returns to its original colour. With a piece of wood, or glass, scrape off the dark deposit from the walls of the tube. It is seen to be bright metallic quicksilver or mercury.

(*b*) Place a little potassium chlorate in a test-tube, and heat it. Observe that the mass crackles, melts, and gives off a gas. Test by a glowing match, and see that the gas is *oxygen*. The gas is, however, given off more readily, and without fusion, if a little manganese dioxide is added to the chlorate. By this means some jars of the gas can be collected.

(*c*) Fit a delivery tube *B* to a flask *A*, and in the flask put a mixture of potassium chlorate and manganese dioxide (Fig. 201). Let the end of the delivery tube dip under water contained in the trough *C*. Fill several jars with water and invert them in the trough. Heat the flask, and when the gas is being evolved place the mouth of the jar *D* over the end of the tube so that the gas displaces the water. When all the jars are full take out the delivery tube from the water, and leave the flask for further examination.

(*d*) Heat the mixture in the flask well, till no more oxygen is given off. Boil up the mass with water and filter it. The manganese dioxide remains unchanged on the filter paper. Evaporate the solution to dryness, and there remains a white solid which is not potassium chlorate and which tastes something like salt.

Oxygen—The Active Constituent of Air.—We must now endeavour to obtain and examine the active part of the air which disappeared during the rusting of the iron. Knowing now that is present in the rust, the most evident plan would be to endeavour to obtain it from this source. The ease with which iron rusts, that is the readiness with which it takes up the active part of the air, should indicate that it would probably be very difficult to obtain it from this source, and that some other rust which is more difficult to prepare would probably be better for our purpose. The most convenient is the rust of mercury, which is a red powder not easily formed. It can be obtained if mercury is heated for a considerable time in air, when it forms as a red scum upon the surface of the metal. The changes which occur when this rust is heated should be carefully described in a note-book.

Action of Heat on Red Oxide of Mercury.—When mercury rust, or as it is known to the chemist, red oxide of mercury, is strongly heated, it darkens in colour and a dark deposit of mercury collects above the powder round the inside of the tube in which the heating is done. When a glowing splinter of wood is plunged into the tube it bursts into flame.

What does this experiment teach? It shows that by heating the rust of mercury we obtain mercury itself, and a gas in which wood burns more brightly than in air. Is it what we should expect to find supposing we have obtained the *active part* which we hoped to get? It certainly is, for we have found that the gas occupying the other four-fifths of the air does not support combustion at all, and thus acts as a diluent. Consequently the active part itself would be expected to support combustion very vigorously.

Absolute proof is, however, forthcoming. It may be proved, by weighing, that the mass of the original mercury is equal to that left after the experiment, provided that all the rust is decomposed and no mercury is lost. This shows that the gas escaping from the rust is the same gas as that taken from the air. This change may be thus stated:—**Oxide of mercury, when heated, decomposes into mercury and oxygen.**

Preparation of Oxygen from Potassium Chlorate.—As the quantity of oxygen obtained by the method just described is comparatively small, and the oxide of mercury is expensive, a more convenient source of the gas is the white crystalline powder called Potassium Chlorate.

This white crystalline compound is made up of three elements—potassium, chlorine, and oxygen—and if heated in the same way as the red oxide of mercury it melts and gives off bubbles of oxygen, and after all the oxygen has been given off a white substance like table salt is left behind.

By heating the potassium chlorate we have broken it up into two things, the gas collected in bottles and the white substance like common salt, which is called potassium chloride, left behind and containing no oxygen.

POTASSIUM CHLORATE gives when heated POTASSIUM CHLORIDE and OXYGEN.

Use of Oxygen Mixture.— By adopting a slightly different method, oxygen can be obtained more readily and easily, for it has been found that by mixing the potassium chlorate with certain other substances, of which one is a black compound, manganese dioxide, the oxygen from the chlorate comes off more easily and at a lower temperature. This mixture may be called *oxygen mixture.* If after all the oxygen has been driven out of the mixture the residue left behind is boiled up with water in a flask and the turbid liquid filtered, the manganese dioxide remains unchanged on the filter paper. What, then, is the use of the manganese dioxide?

This question is one which was for a long time explained by calling the manganese dioxide a *catalytic agent*, and such actions, viz., those accelerated by the presence of a substance, which itself does not change, were called *catalytic actions.* In reality, however, the manganese dioxide goes through a series of changes, but the final one leaves it in its original condition.

Properties of Oxygen.

EXPERIMENTAL WORK.

The jars of oxygen prepared as described in Experiment 177 (*c*) are required.

178. *Physical Properties of Oxygen.*—Take one of the bottles of oxygen (one of those collected last should be chosen). Notice everything you can about the contents of the bottle. It is a *gas* with *no colour.* Remove the plate from the mouth and test its smell; it has *no smell.* Try the taste by breathing some of the gas; it has *no taste.* See if the gas has any effect on moistened litmus-papers, one blue and the other red. There should be no effect; we say oxygen is a *neutral* substance.

179. *The Burning of a Candle in Oxygen.*—Attach a piece of stout wire to a wax taper as shown in Fig. 202, and having lighted the taper plunge it into another of the jars of oxygen (Fig. 203). Notice that it is *not extinguished*, but continues to burn, but with a *larger* and *brighter* flame.

180. *The Burning of Charcoal in Oxygen.*—Into another jar of oxygen thrust a splint of wood red-hot at the end, or a piece of red-hot charcoal placed in a deflagrating spoon (a small upturned iron spoon with a long handle) (Fig. 204). Note the brilliancy of the combustion. Now pour into the jar some clear lime water (*i.e.* some of the clear liquid which is formed if lime and water be shaken together and allowed to stand. It is really a solution of lime in water). Notice that it turns milky owing to a white powder being diffused through the liquid.

181. *The Burning of Phosphorus in Oxygen.*—In another jar burn a piece of phosphorus about half the size of a pea, contained in the defla-

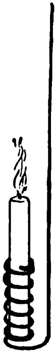

Fig. 202.—Candle supported for burning in oxygen.

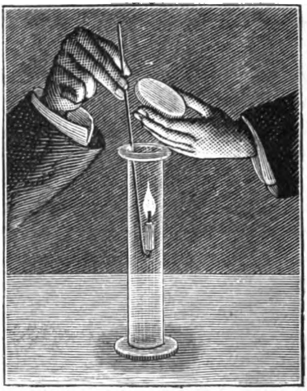

Fig. 203.—Increased combustion in oxygen.

grating spoon. Note the great brilliancy of the combustion and the dense white fumes. Add water and shake—the fumes dissolve. Into the solution put a blue litmus paper. Observe that it is turned *red.*

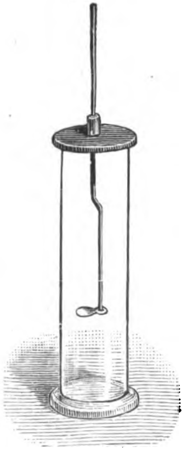

Fig. 204.—Jar with deflagrating spoon in it.

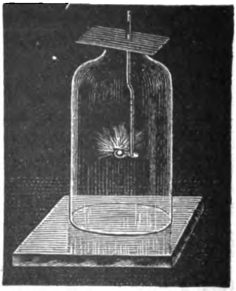

Fig. 205.—How to burn phosphorus or sulphur in oxygen.

182. *The Burning of Sulphur in Oxygen.*—Perform, with another jar, a similar experiment with sulphur. There are few fumes, but a strongly smelling gas is obtained, also soluble, turning the blue litmus red.

183. *The Burning of Magnesium Ribbon in Oxygen.*—Ignite a small piece of magnesium ribbon and hold it by means of crucible tongs in a jar of oxygen. Notice the white solid formed. Test its solubility in water, and show that unlike the previous products, it will not turn a blue litmus solution red, but will turn a red litmus solution blue.

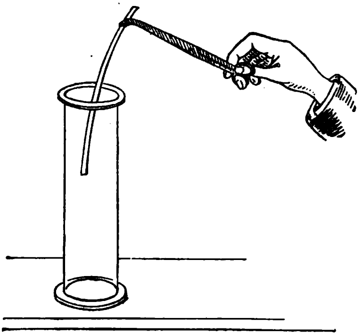

FIG. 206.—How to burn magnesium ribbon in oxygen.

184. *The Burning of Sodium in Oxygen.*—Put a small piece of sodium[1] in a dry deflagrating spoon, light the sodium, put it into another jar of oxygen. Observe the fumes formed. Dissolve these in water and try the effect of the solution on litmus paper. It does not turn the blue colour to red, but has exactly the reverse effect, and changes red litmus to blue. Feel the water; it has a soapy feel.

185. *The Burning of Iron in Oxygen.*—Obtain a piece of iron wire (a thin steel watch spring will do), and dip one end into a little melted sulphur, and when the sulphur is burning place the wire in another jar of oxygen. Observe that the sulphur burns and also starts the combustion of the iron which continues to burn with a brilliant shower of sparks. After the burning has ended, observe that a quantity of an insoluble solid (iron rust) has been formed.

186. *Oxygen is soluble in an Alkaline Solution of Pyrogallol.*—(*a*) Collect some oxygen in a small test tube over mercury. Dissolve a little caustic potash in pyrogallol, so as to make a strong alkaline solution.

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[1] Important! Carefully read the note on p. 275.

Force some of the solution into the oxygen by partly filling a bent pipette with it, and blowing down the pipette when the bent end is under the bottom of the test-tube, as shown in Fig. 207.

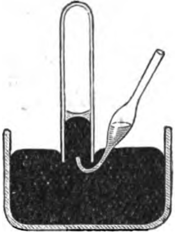


FIG. 207.—To illustrate Experiment 186.

Note that after a little while the oxygen is wholly absorbed.

(*b*) Repeat the last experiment, substituting air for oxygen, and notice that the air is only partially absorbed.

Properties of Oxygen.—Oxygen is a gas which has no colour, no smell, no taste. It has no action upon litmus paper and is for this reason said to be neutral. As the rekindling of a glowing splinter of wood and the increased brightness of the flame of a candle burning in oxygen show, ordinary combustible substances burn more brightly in oxygen than in the air.

Oxygen has no effect on substances like sulphur and carbon, when they are at the same temperature as the room, but if these elements are heated to the point of ignition, the oxygen *combines* with them very readily, causing them to burn vigorously.

Some substances which will not burn under ordinary conditions can be made to burn in oxygen, and the case of iron affords a good example of this. The student should think of what the result would be if there were only oxygen in the air. As soon as the iron got red-hot it would start burning. We could not in these circumstances use iron for our grates, furnaces, and similar things. Oxygen is not very soluble in water—one hundred parts of water dissolve three parts of this gas. That the amount of oxygen dissolved by water is very small is seen by the fact that we can collect oxygen over water as in Expt. 177 (*c*). But though the amount is small it is of great importance in the economy of nature, for it is due to this dissolved oxygen that water animals are able to breathe. Oxygen can, however, be readily dissolved by some liquids, such as a solution of pyrogallol in caustic potash.

Though oxygen exists in a gaseous condition under ordinary conditions of temperature and pressure, yet it can, by lowering the temperature and very much increasing the pressure, be made to assume the liquid condition. It is sixteen times as heavy as hydrogen, and a little heavier than the air. It is indispensable to life. It is the constituent of the atmosphere which is used up in the processes of combustion, decay, and fermentation.

Formation of Oxides Explained.—Whenever oxygen combines with another element an oxide is formed. Indeed, oxygen is so active and powerful an element that it forms oxides with every element except fluorine.

In all the cases of burning studied experimentally under the properties of oxygen, new substances with new properties have been formed; they are therefore chemical compounds and the experiments afford instances of chemical action. Taking some of the experiments performed as examples, when sulphur burns in oxygen a compound which has a peculiar smell and reddens a blue litmus-paper is formed, it is called Sulphur Dioxide.

SULPHUR burning in OXYGEN forms SULPHUR DIOXIDE.

Similarly when carbon burns in oxygen, a gas which extinguishes a burning taper and turns lime-water milky is formed. This compound is known as Carbon Dioxide.

CARBON burning in OXYGEN forms CARBON DIOXIDE.

Again, when iron burns in oxygen, a brown powder, which is really ordinary iron-rust, is formed, as well as a brittle-black solid quite unlike the original iron. These compounds are both of them oxides of iron.

IRON burning in OXYGEN forms IRON OXIDE.

Air compared with Oxygen.—We have now seen that when a substance burns in oxygen a new compound is formed, which is an oxide. But we must go further, and ask—Is this also the case when it burns in air? Does it take away the oxygen and form an *oxide*, leaving the nitrogen unacted upon, as we should expect? This can be readily tested by Experiment 174 (*b*) with phosphorus burning in a confined volume of air.

As was the case in rusting, one-fifth of the air is used, this being what we found was the quantity of oxygen present; the white fumes formed, too, combine with water to make an acid, as when the phosphorus burns in oxygen. In fact, all tests prove the products to be identical. Hence, in air, also, the burning consists of the union of the burning substance with the oxygen of the air to form a new compound—*an oxide.*

It would be easy for the student to verify this by burning in air the different substances which were burnt in oxygen, and carefully comparing the products.

The Air is not a Chemical Compound, but a mixture of gases.—In proof of this statement, the following facts and experiments may be cited :

1. The composition of a chemical compound never varies, while the composition of air does vary slightly.

2. Whenever a chemical compound is formed a certain amount of heat is developed, and there is a change of volume. When, however, oxygen and nitrogen are mixed in the proportion in which they occur in the air (Expt. 176) there is no evolution of heat nor change of bulk, though the mixture cannot be distinguished from air.

3. The proportion in which oxygen and nitrogen are mixed in the air does not bear any simple relation to the combining weights of these elements, whereas in the case of every true chemical compound, the amounts of the constituent elements always bears some simple ratio to these weights.

4. When air is shaken up with water, some of it is dissolved. If air were a chemical compound it would be dissolved *as a whole*, and therefore the dissolved part would have the same composition as the un-dissolved part. But this is not found to be the case. The air dissolved in water can be expelled by heat, and if it is collected the oxygen in it is found to be more in proportion to the nitrogen than it is in ordinary air, thus showing that water dissolves more oxygen than nitrogen.

Ordinary air consists of about one-fifth oxygen, four-fifths nitrogen ; but air expelled from the water contains about one-third oxygen and two-thirds nitrogen.

5. When air is liquefied by intense cold and great pressure, and the liquid air is then permitted to evaporate, the nitrogen is first given off, so that the liquid becomes richer and richer in oxygen. If air were a compound, no one part of it would be more volatile than the other.

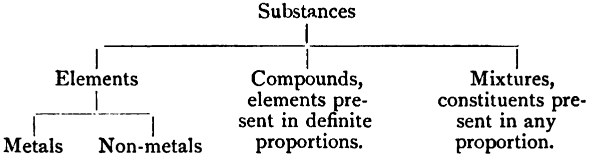
Chief Points in Chapter XVII

Physical Changes are those in which the composition of the body experiencing the change remains unaltered. The science concerned with these changes is called **Physics.**

Chemical Changes are those which result in the formation of new substances with new properties. The study of such changes is called **Chemistry.**

Chemical Elements are kinds of matter which can, by no known means, be broken up into anything simpler. They can be sub-divided into **metals** and **non-metals.**

Compounds and Mixtures.—


Substances
Elements
Metals
Non-metals
Compounds, elements present in definite proportions.
Mixtures, constituents present in any proportion.

In a **mixture** the components exist side by side and can be separated by simple mechanical methods. The ingredients may be present in any proportion and the properties of the mixture are intermediate between those of the constituents.

In a **compound** the components cannot be separated by the simple means available in the case of mixtures. The properties of the compound are quite different from those of the constituents and those constituents are always present in certain definite proportions which for each compound are invariable.

Iron gains in mass during rusting, taking some material from the air, and this material is the part of the air concerned in burning. These facts were found out and established by the series of experiments which the reader has, it is presumed, either performed or seen performed.

Nitrogen is the inactive part of the air. It makes up 80 per cent. (roughly) of the atmosphere. It is a very inert element. It does not burn, nor will it allow other things to burn in it. It can be made to unite with a few metals, such as magnesium and lithium, forming *nitrides*.

Argon is another very inert element, which was discovered in 1894. It makes up about 1 per cent. of the air.

Oxygen is the active part of the air. When red oxide of mercury is heated it decomposes into mercury and oxygen. This gas can also be obtained by heating potassium chlorate. The oxygen is given off from this substance more readily if it is mixed with manganese dioxide before being heated. The substance left after driving the oxygen out of potassium chlorate by heating it is called potassium chloride and is very like common salt.

Oxides.—When some elements are heated in oxygen they unite with it, forming **oxides**. Thus—

Iron and oxygen form Oxide of iron.
Phosphorus and oxygen form Phosphorus pent-oxide.
Carbon and oxygen from Carbon di-oxide.
Sodium and oxygen form Sodium oxide.

Some oxides unite with water to form **acids** which turn blue litmus red ; the oxide of phosphorus is an example.

Other oxides unite with water to form an **alkaline solution** which has a soapy feel ; the oxide of sodium is an example.

Gain of Mass during Burning.—It has been seen by performing experiments with phosphorus, sulphur and magnesium, that there is always a gain in mass when a substance is burnt. Thus, phosphorus gains about 128 per cent., sulphur 100 per cent., and magnesium 66·5 per cent.

Combustion and Rusting.—These are essentially similar. The only difference is that combustion is attended with the production of **light,** due to the high temperature to which the products are raised by the heat of the chemical action.

QUESTIONS ON CHAPTER XVII

1. Ancient philosophers regarded earth, air, fire and water as the four elements of which our world is composed. What has modern chemistry to say as to the nature of these so-called elements?

2. Describe experiments to illustrate the combustion of three different substances in oxygen. Name the compound formed in each case, and state how its existence may be demonstrated.

3 Describe some differences between a chemical compound and a mixture. Gunpowder is a mixture of nitre, sulphur and charcoal. How can these ingredients be separated from one another?

4. When a candle burns in air, certain substances are produced which differ from the wax of the candle and from air. How would you prove this to a class?

5. The inside of a glass bottle is moistened with water and well smeared with clean iron filings. The bottle is allowed to stand for a day or two upside down and with its mouth under water. What changes will be found to take place (1) in the iron filings, and (2) in the air in the bottle?

6. What is the "rust" of iron?

Name some metal that will not rust.

A piece of sodium is thrown into water, what will happen?

7. Which of the following bodies are "elements"?—Air, chalk. coal-gas, diamond, iron, mercury, salt, soot,, sulphur, water.

Give your reasons for thinking that any one of the ten is not an element.

8. Oxygen and nitrogen are the two chief ingredients in common air. State reasons for the usual belief that they are not combined together chemically.

9. Which of the following substances are elements, which chemical compounds, and which mixtures, and what are the elements of which they are composed?—Air, hydrogen, quartz, gunpowder, lime, nitrogen, charcoal, iron.

10. What are the chief properties of oxygen?

Describe the experiments you would make to illustrate these properties.

11. Explain the terms Mixture and Compound. How would you show that iron and sulphur can exist together, either as a mixture or as a chemical compound?

12. State in general terms the differences observable between a mixture and a compound of any two substances. Use air and water as illustrations.

13. Describe experiments to show whether air is a mixture or a chemical compound.

CHAPTER XVIII

WATER AND HYDROGEN.

WE must next turn our attention to *water* and endeavour, as we did in the case of air, to investigate its chemical composition and other characteristics.

Water.

EXPERIMENTAL WORK.

187. *Action of Heated Iron on Water.*—Place some iron filings in the hard glass tube CA, and let the end A dip under water. To the end C fit a delivery tube from a flask containing water previously boiled to drive off the dissolved air. Heat the iron filings well, and boil the

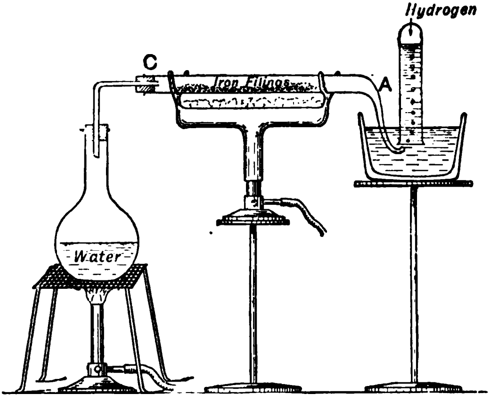


FIG. 208.—Steam passed through a tube containing iron nails or filings heated to redness gives a gas which can be collected over water, and is inflammable.

water in the flask so that the steam passes over the heated iron, and then into the water, where it condenses. Now place over the end A an inverted test-tube of water, and note that the steam is not completely condensed, but that minute bubbles ascend to the top of the test-tube. When you have so obtained a sufficient quantity of gas (half a small test-tube), first disconnect C from the flask of water, then stop the boiling. Close the end of the test-tube with your thumb, and holding a lighted match to the mouth, open the tube. Observe that the gas *burns*. Examine the iron filings in the tube CA, and see that a quantity of rust has been formed.

188. *Action of Sodium on Water.*—Place a small piece of sodium[1] in water in an evaporating basin, and observe the action. Feel the water left after the sodium has all disappeared, and test it with red litmus. Evaporate away the water. Note the residue.

189. *Collection of the Gas which Sodium turns out of Water.*—Place a small piece of sodium in a small piece of lead tubing, the ends of which are nearly closed, and drop into water (or place down over the sodium a thimble with holes in the top). A gas is seen to come off. Collect this in an inverted tube full of water, and by this means obtain three test-tubes of the gas, and observe that it is colourless and odourless (Fig. 209).

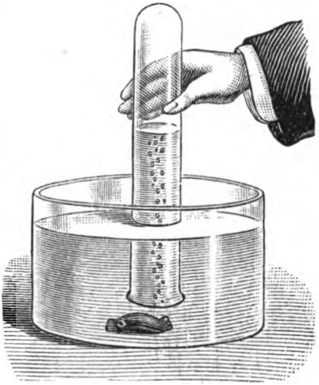


FIG. 209.—Hydrogen is given off when sodium acts upon water.

190. *Examination of the Gas produced by the Action of Sodium upon Water.*—Take out two of the tubes and hold them for the same time, say 30 seconds, (1) with mouth up, (2) with mouth down. Then apply a light to the mouth of both.

Now try the 3rd tube, holding it mouth down, and place a lighted match up into the tube. Note that the gas does *not* explode, but burns quietly, while the match is extinguished.

Chemical Examination of Water.—Before proceeding to study the chemical behaviour of water it will be well to run over what has been already learnt about it. Water is a clear liquid with a blue-green colour, which is best seen by causing light to pass through a considerable length of it. It boils at 100° C., and is then converted into steam. It freezes at 0° C., becoming ice. Its density, *i.e.*, mass of 1 c.c., is 1 at 4° C. and slightly less at any other temperature, owing to the fact that water expands when either cooled below or heated above 4° C. It has the power of dissolving many substances, *e.g.*, salt, sugar, &c., forming solutions from which the water may be evaporated away, leaving the solid behind. But these facts tell us nothing of the chemical nature of water because we have no changes in composition. The water, present all the time, is not converted into any new product. We must therefore try to get a new product from the water. We must first try the action of metals, and as in the case of our studies upon air, we will use iron first. If iron be left in water it is found to form a considerable quantity of *rust*; but this may be due to the air which may be dissolved in water; for if the iron be placed in a tube, containing water which has first been well boiled to drive off the air, and the tube is then sealed in a blow-pipe, the iron either does not rust, or does so to only a very slight extent.

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[1] Great care must be taken when using sodium, which must never be allowed to touch damp materials. It is kept under naphtha until used, and should never be handled with the fingers. It should be dried by blotting paper when taken from the bottle and cut with a clean knife, the pieces not used being immediately replaced in the bottle.

If, however, the iron is heated and the water is passed over it in the form of steam, in the manner described in Experiment 187, a chemical action begins which teaches several important facts about the composition of water. Not only do the iron filings become rusty, just as they do when exposed to damp air, but a gas, insoluble in water and which can be collected over a trough as shown in Fig. 208, is obtained. This gas burns when a lighted taper is brought near to it.

Action of Sodium upon Water.—It has been seen that from the steam and iron we obtain iron rust, that is, iron oxide, and an inflammable gas. We must investigate this further, as it appears to show that the water contains this inflammable gas as well as oxygen. Something must be found which has a more powerful action on oxygen than the iron. Such a substance is the metal sodium.

When a small piece of sodium is thrown upon water it swims about on the surface with a hissing noise; and the solution, after the sodium has all disappeared, has a soapy feel and turns red litmus blue. In this case we can only see that the action is energetic and a new product is formed, while the soapy feel of the water and its action on litmus appear to indicate that this product is the same as that obtained when sodium is burnt in oxygen and the fumes formed are dissolved in water. If the piece of sodium is enclosed in a piece of lead piping, the ends of which are flattened, the gas comes off in such a way that it can be collected with ease, and it is then observed to be colourless and to have no smell. If two tubes, which have been filled with the gas (Fig. 209) and held for thirty seconds, one with its mouth upwards and the other with its mouth downwards, have a lighted match applied to them, it is found that there is no effect with the first tube and a slight explosion with the second.

The slight explosion of (2) shows it to contain an explosive gas, while the absence of any effect with (1) shows that the gas has all disappeared. Hence, it is seen that the gas escapes from a tube held mouth upwards, but not so quickly from one held mouth downwards. It is therefore lighter than air, being in fact the lightest gas known.

If a third tube of the gas is examined in the same way, immediately on taking it out of the water, the gas does not explode, but burns quietly, while the match itself is extinguished.

Preparation and Properties of Hydrogen.

EXPERIMENTAL WORK.

191. *Preparation of Hydrogen.*—Select a flask and fit it up as is shown in Fig. 210. Be very careful that the stopper and the tubes respectively

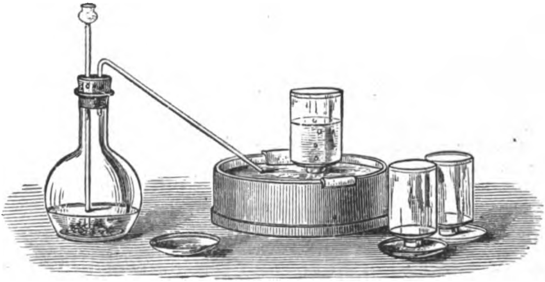

FIG. 210.—An inflammable gas (Hydrogen) is obtained by dissolving zinc or iron in dilute sulphuric acid.

fit very closely. Into the flask put enough granulated zinc to cover the bottom. Pour some water upon the zinc. Arrange the delivery tube in the trough as you did when you were making oxygen. Pour a little sulphuric acid down the thistle-headed acid funnel, and be quite sure that the end of the funnel dips beneath the liquid in the flask. Do not collect bottles of the gas until you are sure pure hydrogen is being given off, which you can find out in this way. Fill a test-tube with water and invert it over the end of the delivery tube. When it is full of gas, still holding it upside down, take it to a flame (which should not be near the flask you are using); notice that there is a slight explosion. Continue this until the hydrogen burns quietly down the test-tube. When this happens you may proceed to fill one or two bottles. When the bottles have been filled, it is better not to remove them from the water until you want to use them. Collect also a soda-water bottle half full of the gas.

192. *The Liquid Left in the Flask.*—Filter off the liquid in the flask from the undissolved zinc (sufficient zinc should be used to leave a quantity still undissolved; if all has disappeared add more and wait till the action ceases). Partially evaporate the liquid and allow it to crystallise. You will find that a quantity of clear colourless crystals are formed. Examine them and sketch the most perfect. Heat some of the crystals in a tube and observe that they melt, give off water (which can be collected and proved to be water), and leave a white powder.

193. *Water of Crystallisation.*—Examine crystals of blue vitriol. Powder one and heat the powder in a dry test-tube, and notice that water collects on the sides of the tube. The blue vitriol becomes white as it loses water. Dry a larger quantity of blue vitriol in an oven till white. Pour water upon some of the white powder thus formed. Notice it regains its original blue colour with the evolution of heat.

194. *Hydrogen burns but extinguishes a flame.*—Test one jar of the gas by means of a lighted match or taper. Observe that the gas burns around the mouth of the jar but that the taper is extinguished, but on being taken out, again becomes alight on passing through the flame of the burning hydrogen (Fig. 211).

195. *Hydrogen is lighter than Air.*—Take a full jar of the gas and hold it mouth upwards below a second smaller jar held mouth downwards as shown in Fig. 212. On testing with a lighted taper observe that the gas has left the lower jar and filled the upper. Many experiments, as the filling of balloons or soap bubbles, may also be performed to demonstrate the extremely low density of hydrogen.

196. *Hydrogen forms an explosive mixture with Air.*—Wrap your hand well in a duster and with it hold the soda-water bottle. Take it out of the water so that the water runs out, and the bottle is now filled

with a mixture of hydrogen and air. Apply a light and you will not fail to observe that an explosion results.

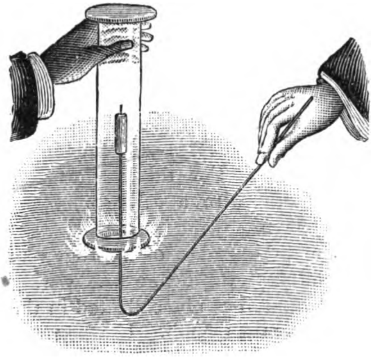

FIG. 211.—Hydrogen burns, but extinguishes a flame.

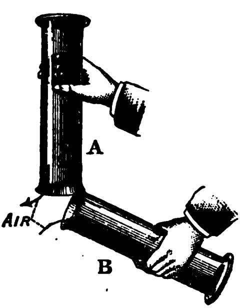

FIG. 212.—Hydrogen is so light that it can be poured upwards.

197. *Hydrogen burns with a pale blue flame.*—Apply a light to the end of the delivery tube and allow the hydrogen to burn. Observe that it burns with a pale blue flame, which after a time becomes yellow. As the colouration does not occur however until the glass becomes hot, we must regard it as due to some substance in the glass.

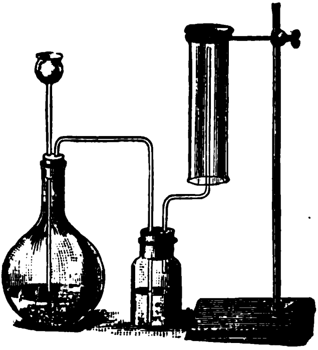

FIG. 213.—Collection of hydrogen by upward displacement.

198. *Hydrogen can be collected by upward Displacement.*—Substitute for the delivery tube in Expt. 191 a tube bent twice at right angles, as shown in Fig. 213, and arrange a jar on a retort-stand in an inverted position. Place a test-tube over the upright tube, and allow it to stay there for a minute, and test the gas as described in Expt. 191. When it is pure, substitute the inverted jar, and after a few minutes lift it off the stand and apply a light, first taking the precaution to wrap a duster round the jar and to hold it away from your face. The jar will be found to contain hydrogen.

Preparation of Hydrogen in Large Quantities.—It has been seen that from water and sodium it is possible to obtain an inflammable gas, lighter than air, which does not support combustion, while there is also formed a solution which behaves like the solution of sodium oxide. The most natural inference is that the water contains this inflammable gas which is called **hydrogen,** and oxygen. Before proceeding to verify this, it will be well to examine more carefully the properties of the inflammable gas, and to do this it is necessary to collect the gas in greater quantity than hitherto. For this purpose we must act upon a metal, such as zinc, with a dilute acid, say sulphuric acid, instead of water.

The apparatus suitable for the preparation of hydrogen in his way is described in the experimental work (p. 277). Owing to the insolubility of hydrogen in water, it can be collected in the same way as oxygen over the pneumatic trough. If when the chemical action in the flask has completely stopped, the liquid is filtered from the still undissolved zinc as previously explained, and then partially evaporated in a basin and afterwards allowed to crystallise, a quantity of clear colourless crystals are formed. These crystals melt if heated in a tube, give off water and leave a white powder. These crystals are a compound formed from the zinc and part of the sulphuric acid, and are known as *zinc sulphate.*

It may therefore be stated that **sulphuric acid and zinc form hydrogen and zinc sulphate**. Or, the same fact may be expressed in another way :—

SULPHURIC ACID when acted upon with ZINC gives ZINC SULPHATE and HYDROGEN.

Water of Crystallisation.—Many crystals behave like zinc sulphate on heating, *i.e.*, lose water which they previously contained, and become converted to a powder. The water contained in a crystal and evolved on heating is known as *water of crystallisation.* Some substances, like blue vitriol (copper sulphate), change in colour when their water of crystallisation is driven out by heat. But the colour can be regained by adding water.

Properties of Hydrogen.—We have now a means of obtaining hydrogen in considerable quantity and have observed that it is a colourless, odourless gas, considerably lighter than air ; it burns, but does not support combustion, and it forms a highly explosive mixture when mixed with air. It is now necessary to obtain and examine the compound which is produced by the burning of hydrogen, that is, the oxide or hydrogen.

When Hydrogen Burns, Water is Formed.

EXPERIMENTAL WORK.

199. *Water is Formed by Burning Hydrogen.*—(*a*) Arrange a flask as before for the production of hydrogen. Pass the gas through a tube containing chloride of calcium in order to thoroughly dry it. Allow it to burn under a retort which is kept cool by a stream of water flowing in at the tube and out at the end of the neck (Fig. 214). Observe the formation, on the side of the retort, of a clear liquid which collects and drops into a beaker placed to receive it. By this means sufficient of the liquid can be obtained to identify it, especially if several students add together the liquids formed in their experiments.

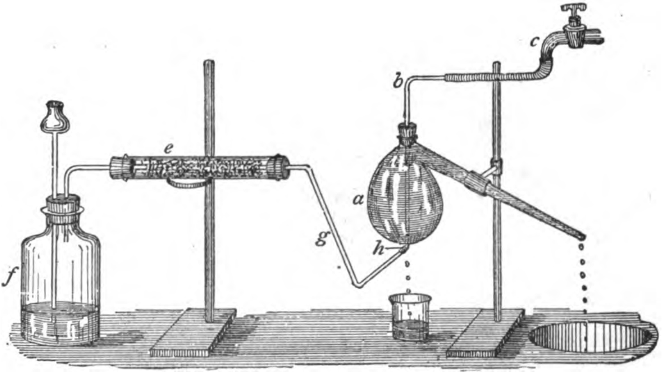

FIG. 214.—Water is produced when hydrogen burns in air.

(*b*) Take the density, freezing point (a mixture of sodium sulphate and hydrochloric acid forms a very convenient freezing mixture), and boiling point of the liquid formed by burning hydrogen. You will find these are 1, 0° C., and 100° C. respectively, and these results are sufficient to enable you to state that the liquid is identical with pure water.

200. *Analysis of Water.*—This may be done by means of an electric battery for generating the electric current, and a **Voltameter.** The latter is most simply made by closing the bottom of a funnel by means of a tightly fitting cork through which pass two platinum wires with small plates of platinum attached to the ends remaining in the funnel (Fig. 215.) Over these plates are supported two glass test-tubes, and the tubes and part of the funnel are filled with water to which has been added a little sulphuric acid, as otherwise it offers great resistance to the electric current. The wires from a battery of three or four cells are connected with the ends of the platinum wires, and as soon as the connection with the battery is complete, provided there is clean metal at every junction, bubbles of gas are seen to rise from each platinum plate and to ascend into the tube and displace the contained liquid. After the experiment has gone on for half-an-hour, the gases may be tested and their volumes measured. It will be found that the volume of one gas is double that of the other, and that the gas of which there is the larger amount is *hydrogen*, while the other is *oxygen*.

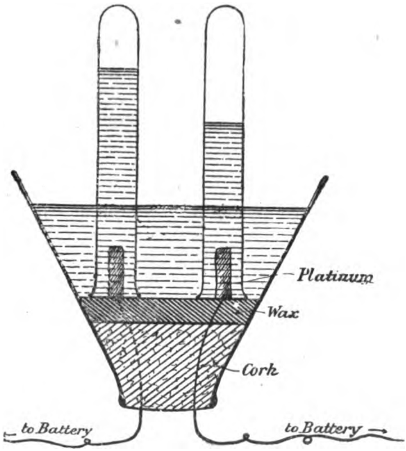

FIG. 215.—A Voltameter.

Formation of Water by Burning Hydrogen.—When a jet of burning hydrogen is brought in contact with a cold surface, as in Fig. 214, the product of combustion, or the oxide of hydrogen, is condensed. If after a sufficient quantity of the liquid has been collected it is examined, it is found (*a*) to have a density of 1, (*b*) to freeze at 0° C., and (*c*) to boil at 100° C. These are the physical characteristics of water, so we are justified in stating that this liquid is water.

Previous experiments have indicated that water contains hydrogen and oxygen. We have found it is an oxide of hydrogen, and may now write:—**Hydrogen in burning produces water which is, therefore, an oxide of hydrogen.**

Proportions of Oxygen and Hydrogen in Water.—The proportions in which the oxygen and hydrogen combine during the formation of water need now to be considered. We may do this in either of two ways, viz., by finding the mass of the gases, or by finding the volume of the gases, which combine. For the latter it is necessary to measure out definite volumes of oxygen and hydrogen, cause them to combine, then measure the volume of gas which remains uncombined and ascertain which gas it is. This is usually done in a piece of apparatus known as an **Eudiometer** (Fig. 216). In its simplest form this consists of a long glass tube closed at one end and graduated in equal volumes, usually cubic centimetres, by divisions marked on the glass. Through opposite sides of the tube, at the closed end, pieces of platinum wire are passed and fused into the glass, being so arranged that they do not quite touch one another. Outside the tube the platinum wires are bent into loops to which wires from an electric coil may be attached.

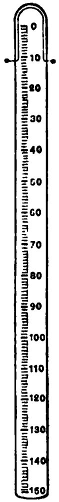

FIG. 216. Eudiometer.

Composition of Water by Volume.—To use the eudiometer it is first completely filled with mercury and inverted over more mercury contained in a trough. A suitable quantity of pure dry oxygen is then bubbled into the tube and the volume (after the necessary corrections for temperature and pressure) is recorded. Pure dry hydrogen is next bubbled into the tube, using a considerable excess of one or other of the gases. The volume is again recorded (with necessary corrections as before) and then, keeping the eudiometer firmly pressed upon a sheet of india-rubber, or felt, at the bottom of the trough, the gases are made to combine by causing an electric spark to pass between the platinum wires inside the tube. As soon as the spark passes, the two gases combine, with a flash of light. The eudiometer is slightly raised from the india-rubber (but of course not above the mercury in the trough), and it is seen that the volume of the gas in the eudiometer is less than before the explosion, and that there is a film of moisture upon the interior of the tube. The corrected volume is again recorded and the nature of the gas ascertained. The volumes of the gases which combined in the manner indicated were found in one experiment to be as follows :—

Corrected volume of oxygen = 12 c.c.
Corrected volume of mixed gases = 50 c.c.
Therefore corrected volume of hydrogen = 38 c.c.
Corrected volume after explosion = 14 c.c.
Gas left ascertained to be Hydrogen.

Hence the 12 c.c. of oxygen united with (38–14), *i.e.*, with 24 c.c., of hydrogen, and this result is always obtained, namely, **2 volumes of hydrogen combine with 1 volume of oxygen to form water.**

If instead of doing the experiment in the above manner the eudiometer tube be kept heated above 100° C. during the experiment (by surrounding it with a larger tube through which the vapour of some boiling liquid is passed), it is further found that the steam produced from these 3 volumes of oxygen and hydrogen only occupy 2 volumes. Such a process as this, the formation of a compound from elements, or from simpler materials, is known as a **synthesis**.

The required ratio may also be found by the **analysis** of water, that is, by breaking the liquid up into its components, which can be done by passing an electric current through it. The apparatus employed is called the **Voltameter** and is described on p. 282. Experiments with this instrument again prove what was found by synthesis, viz., that 2 vols. of hydrogen combine with 1 volume of oxygen, and further, it may be noticed that both classes of experiments also prove that water is solely formed from these two gases, and contains no other constituent.

Composition of Water by Mass.

EXPERIMENTAL WORK.

201. *Composition of Water by Mass*—In the glass tube AC (Fig. 217) place a small porcelain boat containing copper oxide, the boat and oxide being previously weighed. To the end C attach a

U-tube containing calcium chloride, a substance which readily absorbs moisture. At A attach a tube, as shown, by means of which dry hydrogen, prepared as in Expt. 191, may be passed through the tube AC. The U-tube of calcium chloride must be carefully weighed before the experiment. When the hydrogen is passing, heat the tube AC, and observe that the black colour of the copper oxide changes to the red colour of metallic copper, and that water collects in the U-tube D.

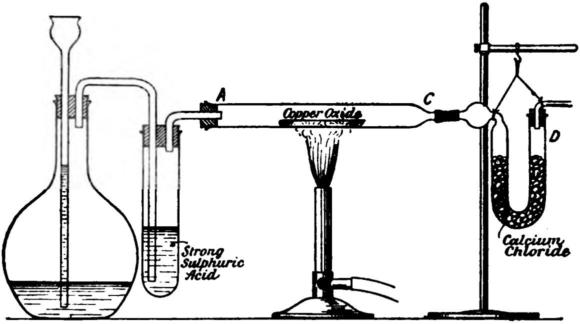

FIG. 217.—When dry hydrogen is passed over hot copper oxide, steam is produced, and the black oxide is converted into copper.

Take care that no condensed water remains in AC; if any is present, heat it and drive it over into D. Allow the tube to cool, disconnect, and weigh the boat of oxide and the U-tube again.

Composition of Water by Mass.—To find the composition of water by mass, that is, the masses of oxygen and hydrogen which combine to form water, it should be noticed that we only require the masses of two out of the three substances concerned, *i.e.*, if we know the masses of hydrogen and water (or of oxygen and water), the mass of the oxygen (or hydrogen) is readily calculated. The experiment is done by finding the masses of the oxygen and water, and for this it is best to use not oxygen itself, but some oxide which readily gives up its oxygen to the hydrogen, so that by weighing the oxide before and after the experiment we can ascertain the mass of oxygen which it has lost. The oxide used for this purpose is oxide of copper, a black powder, which it has been seen is obtained when air is passed over red hot copper. Pure dry hydrogen is passed over the heated oxide when it combines with the oxygen of the oxide to form water and leaves the copper behind. The weighings to be made have already been described, and the method of calculating the result is as follows :—

Mass of U-tube after experiment	36·473 grams
Mass of U-tube before experiment	35·821 grams
Mass of water produced	0·652 gram

Mass of boat of copper oxide before experiment ...	5·562 grams
Mass of boat of copper oxide after experiment ...	4·982 grams
Mass of oxygen	0·580 grams

The mass of oxygen is 0.580 gram, and that of the water produced from it is 0·652 gram; therefore the mass of hydrogen must be 0·652–0·580 gram, that is, 0·072 gram. Write therefore :—

Mass of water	0·682 gram
Mass of oxygen	0·580 gram
Mass of hydrogen ...	0·072 gram

Therefore ·072 gram hydrogen combines with ·580 gram of oxygen, and hence 1 gram hydrogen combines with $\frac{\cdot580}{\cdot072}$ = 8 grams of oxygen.

If the experiment is carefully performed this is the result always obtained, so that we have found that **Water is formed of eight-ninths its mass of oxygen with one-ninth its mass of hydrogen.**

This experiment, also taken in conjunction with the previous experiments upon the volumes of the gases, proves further that one volume of oxygen is 16 times as heavy as the same volume of hydrogen, so that one litre of hydrogen has a mass of $\frac{1\cdot4}{16}$, that is, nearly ·09 gram (accurately ·0896).

Solvent Powers of Water.

EXPERIMENTAL WORK.

202. *Solution.*—(*a*) Place a piece of sugar in water, and note that it soon disappears, and gives a sweet taste to the whole of the water, so that the particles of the sugar must be spread through the entire mass of the water.

(*b*) Weigh out 50 grams of each of the following substances :—finely powdered nitre, sugar, salt, and to each add water, in small quantities, with vigorous shaking after each addition. Determine thus the quantity of water necessary to form a saturated solution of each.

(*c*) Weigh out an ounce each of sugar, common salt, and powdered gypsum. By increasing the amount of water ascertain how much is necessary to completely dissolve each of the powders. Show the amounts of water are roughly 1 ounce, 3 ounces, and 360 ounces (2¼ gallons) respectively.

203. *Solution is a Physical Change.*—(*a*) Weigh out a quantity of salt in an evaporating basin and dissolve it in water. Heat gently over a Bunsen burner so that the water boils and evaporates away completely. Note that a white solid remains in the basin, and again weigh. Satisfy yourself that the mass is equal to the mass of the basin and salt before solution, and that the solid left is still salt.

(*b*) Evaporate a little distilled water in a platinum or porcelain crucible. Notice the absence of any residue. Repeat the experiment with tap-water, and note the residue.

204. *Effect of Temperature on Solution.*—Place a quantity of powdered nitre in water and allow it to stand for some time with frequent vigorous shaking, so that a cold saturated solution is formed. Now heat the solution and see whether more solid dissolves or not.

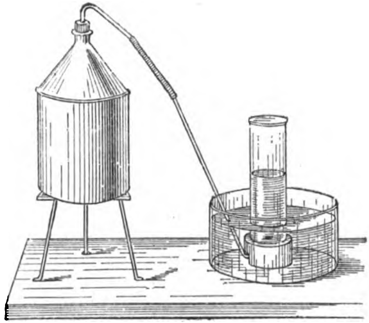
FIG. 218.—Apparatus for expelling air from water.

205. *Gases Dissolve in Water.* — Completely fill a gallon tin can with tap-water and attach a cork and delivery tube, dipping under a jar of water inverted in a trough (Fig. 218). Heat the can and observe that dissolved air is driven out. Collect the air and see that, since it supports combustion, it contains oxygen. Prove also (by means of lime-water) that it contains carbon dioxide.

Water as a Solvent.—If a piece of sugar is put into water it soon disappears, and the liquid is found to be sweet in every part. The sugar has *dissolved* to form a *solution* of sugar. Similarly, a very great number of substances dissolve in water, but not all to the same extent. Those substances which dissolve in this manner are called *soluble*, while those which do not are spoken of as *insoluble*.

Water dissolves a larger number of things than any other liquid. This explains why we cannot find pure water in nature. No sooner does rain form than it begins to dissolve various substances ; in its passage through the air it takes up varying amounts of the constituents of the atmosphere, such as carbon dioxide and oxygen, and when the surface of the earth is reached the water dissolves out of the soil and the underlying rocks portions of all the soluble ingredients. The more soluble bodies are naturally dissolved to the largest extent. It will be seen later that the solvent property of water is considerably increased by the presence of the carbon dioxide it obtains in part from the air. When the amount of material dissolved in water is very great, it gives a distinctive character to the liquid, which becomes known as a **mineral water**. Those natural waters which contain a compound of sulphur and hydrogen, called sulphuretted hydrogen, are spoken of as *sulphur-water* ; if some compound of iron is the substance which has been taken up in large quantities, we have *chalybeate* waters formed. *Effervescent* waters have a great amount of carbon dioxide dissolved.

Hard and Soft Waters.—It is a fact familiar to every one that soap lathers very easily in some waters and not at all in others. If rain-water be used, the lathering takes place with great ease, while with the water which is supplied to some towns a lather can only be made with difficulty ; and if we attempt the same process in sea-water there is no lathering at all. *Those waters in which soap lathers easily are said to be soft. When this is not the case the water is spoken of as hard.* The explanation is a simple one. Water, as has been seen, dissolves materials out of the rocks below the soil, and often takes up, among other things, compounds of calcium and magnesium, which unite with soap forming a new compound of an insoluble kind, and in consequence there is no lathering until all the calcium and magnesium has thus combined with soap, after which the solution or lathering of the soap begins. The soap which combines with the dissolved materials is, of course, wasted.

Temporary and Permanent Hardness.—Hard waters differ among themselves. Some can be softened by mere boiling, and when this is the case the hardness is said to be *temporary*. If the hardness is not removed after the water has been boiled, and the water requires the addition of a chemical to soften it, such hardness is termed *permanent*. As has already been mentioned, the presence of carbon dioxide in water gives it the power of dissolving substances which would be otherwise insoluble. Chalk, known to chemists as calcium carbonate, is insoluble in pure water, but in water in which there is carbon dioxide it dissolves to a considerable extent. As soon as this dissolved gas is got rid of, which can be done by boiling, the chalk, being no longer soluble, is thrown down upon the sides of the vessel. It forms in this way the incrustation which is found on the inside of kettles and boilers.

Permanent hardness is due to the presence of dissolved calcium sulphate and other compounds. Since this substance is soluble in pure water, mere boiling will not get rid of it; washing soda, which is a form of sodium carbonate, softens such water as this, by causing the formation of calcium carbonate in the place of the calcium sulphate.

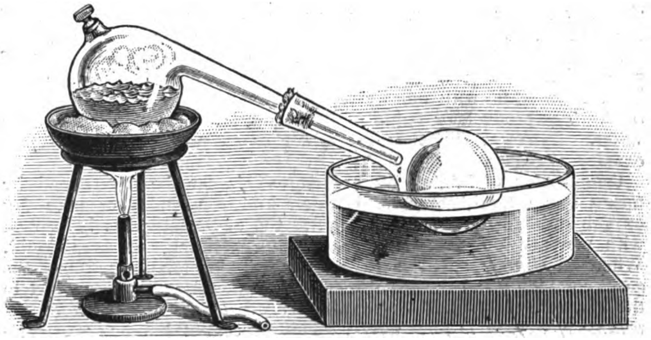

FIG. 219.—The distillation of water.

Distillation of Water.—If the steam which is formed be boiling water containing any of these dissolved substances be condensed, the water formed is quite pure. To obtain pure water from any kind of water, then, whether fresh or salt, all that has to be done is to boil it and condense the steam which is given off. The dissolved materials are all left behind in the vessel in which the boiling takes place. An arrangement for condensing steam or vapour is shown in Fig. 219. The steam driven off from the water in the retort passes into a flask kept cool by resting upon a basin of cold water, and is thus condensed. It is advisable to place a wet duster or a wet piece of blotting paper upon the flask to assist the condensation.

CHIEF POINTS OF CHAPTER XVIII.

Water is a clear liquid with a blue green colour. It boils at 100° C., when it is converted into steam. It freezes at 0° C., becoming ice. Its density at 4° C. is 1. It possesses great solvent power.

Hydrogen is contained in Water.—This has been proved by causing heated iron to drive hydrogen out of the water, when the iron combines with the oxygen which is left, to form oxide of iron. Sodium turns the hydrogen out of water at ordinary temperatures. The hydrogen can be collected and examined.

Preparation of Hydrogen.—Hydrogen is best prepared by acting upon a dilute acid with a metal. Sulphuric acid and zinc have been found to be suitable.

Sulphuric Acid and Zinc form Hydrogen and Zinc Sulphate.

Properties of Hydrogen.—It is a colourless, odourless gas, considerably lighter than air. It does not support combustion, but itself burns in air. It forms an explosive mixture when mixed with air.

Production of Oxide of Hydrogen.—By collecting the product of combustion when hydrogen is burnt, and examining it, it is found to be a clear liquid with density 1, boiling point 100° C., freezing point 0° C. The product, or oxide of hydrogen, is thus seen to be really water. *Hydrogen in burning produces water which is, therefore, an oxide of hydrogen.*

Composition of Water by Volume.—This can be determined by means of an **Eudiometer**, into which known volumes of pure dry oxygen and hydrogen are bubbled after the eudiometer has been filled with mercury and inverted in a trough containing the same liquid. When an electric spark is passed through the mixture parts of the gases combine; and the experiment, when performed, as described in the chapter, shows that *two volumes of hydrogen combine with one volume of oxygen to form water.* This process of building up a compound from its elements is called **synthesis.**

The opposite process of splitting a compound up into its elements is called **analysis.** The analysis of water is effected by passing an electric current through water contained in a voltameter. The result of such an experiment is precisely the same as that obtained, by synthesis, with the eudiometer.

Composition of Water by Mass.—Pure dry hydrogen is passed over heated oxide of copper. The hydrogen combines with the oxygen of the oxide, forming water, and leaves the metallic copper behind. The water formed is collected and weighed. The copper oxide is weighed before and after the experiment. Its loss in mass shows the amount of oxygen in the water formed. The difference between the mass of the water formed and the oxygen it contains shows the mass of the hydrogen in the water. When carefully performed, the experiment proves that *water is formed of eight-ninths its mass of oxygen and one-ninth its mass of hydrogen.*

Natural Waters generally contain dissolved materials. When the amount is very large the water is called a *mineral water.* Natural waters containing sulphuretted hydrogen are called *sulphur-waters*; those containing compounds of iron are called *chalybeate* waters; and those containing much carbon dioxide are spoken of as *effervescent.*

Hard and Soft Waters.—Those waters in which soap lathers easily are said to be *soft.* When such is not the case the water is spoken of as *hard.*

Hard waters which can be softened by boiling are said to have only *temporary* hardness. If the water cannot be thus softened, but requires the addition of a chemical, its hardness is said to be *permanent.*

QUESTIONS ON CHAPTER XVIII.

1. Write down what you consider to be the physical and chemical characteristics of water, that is, the features and properties which are possessed by water, but by no other substance.

2. Describe a chemical method of liberating hydrogen from water (*a*) at a red heat; (*b*) at ordinary temperatures.

If you were provided with three bottles of hydrogen, what experiments would you perform to illustrate important properties of the gas?

3. How can you prepare hydrogen? How would you exhibit its properties to a class? What substance is produced when hydrogen is burnt?

4. A jar of oxygen, a jar of nitrogen, and a jar of hydrogen are put before you. How can you tell which is which?

5. Describe experiments (1) to show that water may be split up into oxygen and hydrogen, and (2) to show that by the combination of these gases water is produced.

6. Describe experiments to show that water dissolves (1) air, (2) lime.

7. Describe some important chemical changes in which water takes the principal part.

8. Give examples of the solvent power of water. How could you determine whether a sample of water contained dissolved solid matter?

Describe the apparatus you would employ to obtain water free from dissolved substances.

9. A current of steam is passed through a tube which contains pieces of iron heated to redness. What chemical change goes on within the tube, and what tests would you apply to identify the gas which escapes from the end of the tube?

10. What is the difference between fresh water and sea water?

Describe, giving a sketch of the apparatus employed, a method of preparing drinkable water from sea water.

11. Describe the apparatus you would use for the production and collection of hydrogen gas; name the materials required, and describe the properties of the gas.

12. Describe three different methods by which hydrogen may be obtained from water.

How would you prove that air contains one of the constituents of water?

13. What are the chief impurities in common water? How would you obtain pure water? Make a sketch of the necessary apparatus and explain the use of its several parts.

14. What chemical reaction takes place when a small piece of metallic sodium is thrown into water?

How would you test whether the solution left is acid or alkaline, and how would you prepare from it some common salt in the crystalline state?

15. If you were given a mixture containing common salt and sand, describe how you would separate these two substances and determine the weight of each which was present in the original mixture.

16. Mention two methods of obtaining hydrogen from water. How would you recognise the gas when obtained?

CHAPTER XIX

CARBON AND SOME OF ITS COMPOUNDS

Forms of Carbon

EXPERIMENTAL WORK.

206. *Carbon is Contained in Organic Substances.*—Heat a series of organic substances, such as meat, wood, potato, egg, &c., in a crucible, and notice in all cases the production of a black residue, consisting largely of carbon. Heat more strongly, and observe that it burns away, leaving an almost colourless ash.

207. *Properties of Carbon.*—Examine and write down the properties of as many of the following forms of carbon as you can obtain:—diamond, blacklead, wood-charcoal.

208. *When Carbon is Burnt Carbon Dioxide is formed.*—(*a*) Heat strongly a piece of charcoal in a closed hard glass test-tube and show that without air it does not burn.

(*b*) Suspend a piece of glowing charcoal in a bottle containing lime-water. Shake up and show that lime-water is turned milky owing to formation of carbon dioxide.

209. *Carbon or Charcoal is Porous.*—(*a*) Show that charcoal floats in cold water. In boiling water charcoal sinks after a time, and then will not float again unless thoroughly dried. This is because air was driven out of the charcoal by the warmth of the water.

(*b*) Fill a large test-tube with ammonia gas[1] over mercury, and show that it can be absorbed by introducing a small lump of charcoal. This is a striking proof of the porosity of carbon.

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[1] Ammonia gas can be easily prepared by heating an ordinary strong solution of ammonia in water (ammonium hydrate). The gas should be dried by passing it upwards through a cylinder of dry quicklime. It can be collected over mercury in a trough.

Forms of Carbon.—Carbon is an element which is very widely distributed in nature, being present in all living matter, and in most products resulting from vital activity.

Carbon occurs, combined with other elements, in many rock masses, being a constituent of all the minerals known as carbonates. Combined with oxygen as carbon dioxide, it occurs in the atmosphere and certain natural gases, or dissolved in spring waters.

In the pure state it exists in various allotropic forms. Or these the purest and the most valuable is the **Diamond.** This form of carbon is crystalline and very hard, being capable of scratching all other minerals. Its refractive index (p. 231) is very high, and on this depends its brilliancy as a gem. Diamond is proved to consist of carbon by burning it in air or oxygen, when only *carbon dioxide* results.

Blacklead or **graphite** is another form of almost pure carbon, with properties totally different from those of the diamond. It is opaque and black, and so soft that it will mark paper. It is really a crystalline form of carbon, although good crystals are not very common. It occurs naturally in mines, chiefly in California, and was formerly largely obtained from Cumberland. Besides its use for lead pencils, it is also used as a lubricant.

Other forms of more or less pure carbon in an **uncrystallised** or **amorphous** state are *coke*, and *gas carbon*, which result from the heating of coal; *lampblack*, which is the carbon deposited by oils, &c., burning in an insufficient supply of oxygen; *wood charcoal*, &c., obtained by heating wood, in closed retorts or in stacks under earth.

Charcoal has the power of absorbing many gases, and also of absorbing colouring matter, and on the latter account it is used for decolorising solutions coloured by organic matter. Coal contains large quantities of carbon, especially the harder or anthracite coals, where the quantity may reach 94 per cent., being, however, only about 65 in brown coal or lignite. *Animal charcoal* is really a misleading term, as the quantity of carbon present is usually only about 10 or 12 per cent., the remainder being chiefly bone ash.

Both animal- and wood-charcoal are very porous substances, and they have the power of absorbing gases to a large extent.

Wood-charcoal is used considerably on the continent for heating purposes. Both kinds are useful in destroying noxious vapours.

Whenever any of the amorphous kinds of carbon burn in air or oxygen, carbon dioxide is the compound formed.

In those cases when, like carbon, the same element assumes forms with physical properties which are quite different, it is said to form an example of **allotropy,** or to have several **allotropic forms.**

Lime

EXPERIMENTAL WORK.

210. *Slaking of Lime.*—To half a pound of fresh lime add three ounces of cold water. Observe that the mass gets very hot and swells up.

211. *Action of Lime on Litmus.*—Test some wet lime with litmus papers. Observe it changes red litmus to blue.

212. *Solution of Lime in Acids.*—Dissolve some lime in hydrochloric acid, and evaporate the solution to dryness. Note the formation of a white solid, which rapidly absorbs moisture from the air and liquefies. It has been previously used in some of our experiments under the name of *calcium chloride.*

Lime.—Lime is a white solid, which is unchanged on heating; but if heated sufficiently, it glows and emits a brilliant white light. It is on this account employed for the production of the limelight, where a small, hard cylinder of lime is strongly heated in an oxy-hydrogen or oxy-coal-gas flame.

Lime is obtained from chalk, or from limestone, the rock being strongly heated in kilns, from which, after the burning, and consequent loss of carbon dioxide, the lime is raked out.

When water is added to freshly-burnt lime, or *quick-lime*, as it is termed, the water combines with it with the evolution of a large amount of heat, which is enough to boil the water if the quantity of lime is large. This can be seen at any time when bricklayers are preparing lime for making mortar. This addition of water to lime is called *slaking* it, and the altered lime is known as *slaked lime.* Lime dissolves to a slight extent in water, forming lime-water.

The Constitution of Chalk.

EXPERIMENTAL WORK.

213. Weigh a crucible and in it place some powdered chalk.[1] Heat it in a muffle furnace at a bright red heat for a few hours, allow it to cool, and again weigh. Calculate the loss or gain for 100 grams of chalk.

214. To a little chalk, or a few small pieces of marble or limestone, in a test-tube, add some dilute hydrochloric acid. Note that brisk effervescence occurs. Fit a delivery tube to the test-tube and pass the gas evolved through lime-water, and observe the formation of a white precipitate resembling that produced by carbon dioxide. To some of the precipitate add a little dilute acid, and observe it becomes clear, with slight effervescence. Evaporate the solution left in the test-tube and see that, as in the case of the action between *lime* and hydrochloric acid (Expt. 213), *calcium chloride* is left.

What Happens to Chalk when it is Heated.—To investigate the nature of chalk, or limestone, a small portion should be heated, and the gain or loss of mass recorded. This can be done if a furnace—a muffle furnace is very convenient—is available.

It will be found that the chalk loses about 44 per cent. of its mass, and it is thus proved that the lime consists of chalk from which some constituent has been expelled by heat.

When hydrochloric acid is added to a little chalk a brisk effervescence occurs and a gas which turns lime-water milky is given off. The powder causing this milkiness dissolves in the diluted acid, and if the solution so obtained is evaporated, calcium chloride is left behind just as when lime is dissolved in hydrochloric acid.

From chalk then, by the action of hydrochloric acid, we obtain carbon dioxide and the product which results from the interaction of the same acid with lime. It appears therefore probable that the chalk consists of the carbon dioxide and the lime.

If hydrochloric acid is poured upon a known mass of chalk, in such a way that all the gas evolved is got rid of, it is found that the loss of mass of the chalk is equal to the loss of mass on heating, so that we are justified in concluding that the same constituent was evolved, and we may write :—

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[1] It is worth while to point out that the prepared substance used for black-board writing is often not chalk.

Chalk = lime and carbon dioxide.

By the action of the gas upon lime dissolved in water we also obtain a white product, and if sufficient of this be collected and examined it is found that by the action of acids it also gives off the carbon dioxide, and that it forms lime on heating. It is therefore chalk, and the formation is merely the reverse of what was written above, *i.e.*, lime and carbon dioxide form chalk, so that the turbidity of the lime-water is due to the formation of chalk.

Compounds which, like chalk, evolve carbon dioxide when acted upon by an acid, are known as **carbonates**, and many carbonates exist, all possessing similar characteristics. Many of these on heating also give off carbon dioxide, the residue being known to be an oxide of a metal, so that they consist of carbon dioxide and a metallic oxide.

This leads to the idea that lime is also the oxide of a metal, and this view is now known to be correct, the metal being named *calcium*. Lime, therefore, is **calcium oxide** and chalk **calcium carbonate**. The action of carbon dioxide upon lime-water may be written

LIME combines with CARBON DIOXIDE to form CALCIUM CARBONATE.

Preparation and Properties of Carbon Dioxide

EXPERIMENTAL WORK.

We are now in a position to prepare larger quantities of pure carbon dioxide, and to study its properties more fully.

215. *Preparation of Carbon Dioxides.*—In a flask fitted with cork, thistle-funnel, and delivery tube (Fig. 220), place some chalk or marble (also a form of calcium carbonate). Pour in some dilute hydrochloric acid, and collect the gas over water as in the case of the preparation of hydrogen, or better, by placing the end of the delivery tube at the bottom of a jar, as in Fig. 220. Collect several jars.

216. *Properties of Carbon Dioxide.*—(*a*) Pass the gas through a solution of lime-water. Observe the formation of the white precipitate

which afterwards disappears. Boil the solution so obtained, and notice the re-precipitation.

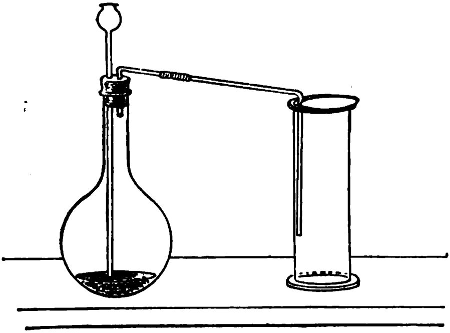


FIG. 220.—The Preparation of carbon dioxide.

(*b*) Into one jar place a lighted taper. Observe that it is extinguished.

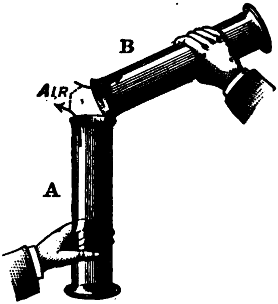


FIG. 221.—To illustrate the high density of Carbon Dioxide.

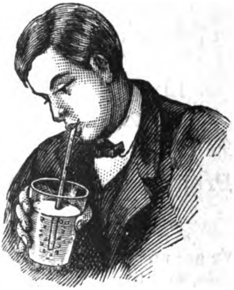


FIG. 222.—To illustrate Experiment 218.

(*c*) Shake up some of the gas with water, and pour the water into some blue litmus solution. The solution turns red. Boil the solution, the blue colour is regained.

(*d*) Pour the gas from one jar (B) into another (A), as shown in the diagram (Fig. 221), and test both jars by a lighted taper. It will be seen that the lower jar contains the gas.

217. (*a*) *Carbon Dioxide in the Air.*—Pour a little clear lime-water into a large bottle of fresh air; shake it about and observe that a slight cloudiness results.

218. *Carbon Dioxide in Expired Air.*—By means of a glass tube breathe into lime-water contained in a bottle or test tube (Fig. 222). Observe that the air from the lungs contains a great deal of carbon dioxide.

Properties of Carbon Dioxide.—It has been seen that carbon dioxide is a heavy gas which does not burn nor support combustion. It is slightly soluble in water, the solution acting as a weak acid and turning blue litmus to a port wine colour, different from the red produced by strong acids.

The solution of the gas may in fact be regarded as containing an acid, carbonic acid, from which the carbonates are derived.

The formation of the white precipitate with lime-water has been shown to be due to the formation of calcium carbonate. The disappearance of this precipitate after the carbon dioxide has been passed into the lime water for some time, is usually explained by the statement that the calcium carbonate is soluble in a solution of carbon dioxide, although insoluble in pure water. From this explanation it follows that the calcium carbonate is re-precipitated when the gas is boiled away. The true explanation most probably is that really a new compound is formed from the calcium carbonate and the carbonic acid, viz., hydrogen calcium carbonate, which is soluble in water, and which decomposes when heated, again forming chalk.

Uses of Carbon Dioxide.—The fact that carbon dioxide is a non-supporter of combustion is made use of in many forms of chemical fire extinguishers, which are generally solutions, which when heated evolve carbon dioxide so that the burning cannot take place and the fire is therefore extinguished.

The solubility of carbon dioxide in water is increased by pressure, and the sparkling nature of the various aërated waters is due to the carbon dioxide with which they have been charged at high pressures, and which escapes when the pressure is reduced to that of the atmosphere by the opening of the bottle. It is also produced during fermentation, the "rising" of bread being due to the escape of carbon dioxide generated by the fermentation of the saccharine matters formed from the starch under the influence of the yeast.

By cold and pressure carbon dioxide may be liquefied and also solidified, forming a soft white substance, which when mixed with ether forms a powerful freezing mixture, the temperature sinking to about − 100° C.

Occurrence of Carbon Dioxide.—Carbon dioxide has been already stated to exist in the atmosphere, and to be produced by the oxidation of animal and vegetable tissues; while further, under the influence of sunlight it is reconverted by the green parts of plants into its constituents, of which the carbon is used by the plant in the formation of tissue. It is also found in many natural gaseous emanations, and is frequently present to a large extent in the gases of caves and underground passages, where, owing to its high density, it tends to accumulate, if formed by fermentation or other natural processes. In expired air carbon dioxide is present to the extent of about 4·7 per cent. Although such air is not again respirable, this is partly due to the diminution of the oxygen, and it is doubtful whether carbon dioxide has any direct poisonous effect. The proportion of carbon dioxide may be increased to even 20 per cent. without immediate serious effects if only the quantity of oxygen be simultaneously increased.

CHIEF POINTS OF CHAPTER XIX.

Carbon is present in all living matter. When organic substances are moderately heated, a black residue largely composed of carbon is left. If the temperature is raised, the carbon burns away and an almost colourless ash is left.

Carbon exists in several **allotropic forms**. Two of these, *diamond* and *graphite*, are crystalline. Non-crystalline or *amorphous* carbon is known in varying degrees of purity as *coke*, *gas-carbon*, *wood charcoal* and *animal charcoal*.

Lime, which is used in making *lime-water*, is a white solid, which is unchanged on heating. But when heated intensely it glows and emits a brilliant white light. It dissolves in hydrochloric acid to form *calcium chloride*. Wet lime turns a red litmus paper blue. Lime is obtained from chalk or limestone by strongly heating either of them. When freshly made it is called *quick lime* which combines with water, evolving much heat and becoming converted into *slaked lime*.

When **Chalk or Limestone is heated** it loses about 44 per cent. of its mass. This is due to the loss of carbon dioxide. The same gas is evolved when either of the substances is acted upon by hydrochloric acid. By ascertaining the mass per cent. of carbon dioxide which is given off by the chalk, we can prove that chalk is really a compound of lime and carbon dioxide.

Carbon Dioxide is a heavy gas which does not burn nor support combustion. It is slightly soluble in water, the solution acting as a weak acid which turns blue litmus to a port wine colour. This solution may be regarded as *carbonic acid* H_2CO_3. The solubility of carbon dioxide in water is increased by pressure. By cold and pressure it may be liquefied and also solidified to a soft, white substance, which when mixed with ether forms a powerful freezing mixture.

Carbon dioxide is always found in the atmosphere, being produced by the oxidation of animal and vegetable tissues. This carbon dioxide is decomposed by the green colouring matter of plants in the presence of sunlight. Carbon dioxide is very common in caverns in limestone regions. Its formula is CO_2.

QUESTIONS ON CHAPTER XIX

1. Describe and explain the changes which take place when (*a*) limestone is burnt in a kiln; (*b*) water is added to some freshly burnt lime.

2. Charcoal burnt in air or oxygen in a bottle containing lime-water produces a white precipitate in the lime-water. This white precipitate if collected and mixed with hydrochloric acid dissolves with effervescence. What experiments would you make in order to compare the gas thus obtained with that obtainable by a similar process from the breath?

3. Describe the apparatus you would use for the production and collection of carbon dioxide gas; name the materials required, and describe the properties of the gas.

4. Three bottles filled with colourless gas are placed before you containing (*a*) hydrogen, (*b*) nitrogen, and (*c*) carbon dioxide. Describe experiments you would make in order to distinguish them from one another, and from other gases.

5. How is lime distinguished from limestone as to composition and properties?

6. What is meant by an allotropic form of an element?

Give examples of allotropic forms, stating in each case in what ways these forms differ one from the other.

7. What is the composition of limestone?

How would you convert limestone into lime, and what other compound would be produced at the same time?

Describe an experiment in which the two substances into which the limestone is split up are caused to re-combine to form a compound of the same composition as limestone.

8. Describe, giving a sketch of the apparatus, how you would obtain a jar full of carbon dioxide gas.

What experiments would you make to exhibit the properties of this gas?

9. Describe experiments to show that charcoal is porous.

10. Four bottles are given you containing oxygen, hydrogen, nitrogen, and carbon dioxide respectively. By what experiments would you distinguish these gases from one another?

11. Describe the appearance of the three different forms of carbon.

By what experiments would you prove that they are really only different forms of the same element?

12. What is the chemical nature of the sediment formed in kettles in which hard water has been boiled, and why is it formed?

If you treat the sediment with hydrochloric acid, what reaction takes place?

CHAPTER XX

SOME FAMILIAR SUBSTANCES.

Iron

EXPERIMENTAL WORK.

219. (*a*) Determine the relative densities, or specific gravities of steel, wrought-iron, and cast-iron by the methods described on p. 68.

(*b*) Recall and, if necessary, repeat the experiments dealing with the rusting of iron on p. 257, and that concerning the burning of iron in oxygen on p. 267.

Iron.—Iron is by far the most important metal known to man. The discovery of how to obtain it from the minerals in which it occurs was probably the most valuable ever made. Though it is very abundant in nature, it is rarely found uncombined. It has been found in certain strange masses, called meteorites, which drop upon this planet from inter-stellar space. In the earth it is found combined with oxygen, forming oxides as *magnetite* and *hæmatite;* as oxides combined with water in *limonite* and *gothite;* with sulphur, as the sulphides, *iron pyrites* and *magnetic pyrites;* with carbon dioxide as the carbonates, *clay iron-stone* and *chalybite;* and other less important ores.

Three Kinds of Iron.—Iron is known and used in three forms, *wrought-iron*, *cast-iron*, and *steel.* The first is almost the pure element, but cast-iron contains also varying amounts of carbon and silicon. Steel contains the same elements as cast iron, but the amount of carbon is considerably smaller.

The different uses to which these varieties of iron are put depends upon the difference in properties they possess.

Wrought-iron is very tough, and can easily be beaten out into plates—a property spoken of as *malleability*. For those articles which are made by hammering the iron into shape, wrought-iron will evidently be used.

Cast-iron is, on the other hand, brittle and easily melted, and consequently is employed in all cases where the article is made by running the molten metal into moulds.

Steel has different properties according to the processes through which it has passed. If it has been heated and then cooled very quickly, it is extremely hard but very brittle; but if cautiously heated and cooled very much more slowly, it is no longer brittle but elastic. This latter process is called *tempering*. Another very important property which steel possesses is that it can be made into a magnet, which will keep its magnetism for a very long time. All the magnetic needles used in telegraphing and in electrical instruments of other kinds are made of steel.

The densities of different kinds of iron are seen from the following table:—

Steel, not hammered	7.82
Iron, bar	7·79
Iron, cast	7·21

Oxides of Iron.—Iron combines with oxygen in several proportions. The following table shows the percentage proportions of the masses of iron and oxygen present in each case:—

Iron Monoxide or Ferrous Oxide	56 of Iron with	16 of Oxygen.
Iron Sesqui-oxide or Ferric Oxide	112 „	48 „
Black Iron Oxide or Tri-ferric Tetroxide	168 „	64 „

The first of these does not occur in nature as a mineral. It combines with acids forming the series of salts known to chemists as *ferrous* salts, one of which, *ferrous sulphate*, is known naturally as the mineral *copperas*.

The second, ferric oxide, is fairly abundant in nature. It constitutes the beautifully crystallised mineral *specular iron ore*, found in Elba. It also makes up the mineral hæmatite, which goes under the names of *kidney ore* and *pencil ore* in the Furness district of Lancashire, according to the shapes which it assumes. It serves as a very valuable source of iron, the noted Barrow steel being derived from it. It is also found in many other parts of Great Britain and other countries.

The black oxide may be regarded as being formed by the combination of the other two. It constitutes the minerals *magnetite* and *lodestone*. It is very often magnetic, though by no means always. It was the magnetic properties of this substance which first made the force of magnetism known to man.

Mercury

EXPERIMENTAL WORK.

220. (*a*) Determine the relative density of mercury by means of a density bottle as described on p. 56.

(*b*) Using the apparatus employed in the experiments described on p. 56 show that a column of mercury one inch high balances a column of water between 13 and 14 inches high. The relative density of mercury is consequently between 13 and 14.

(*c*) Satisfy yourself by trial that (i) an iron key floats on mercury (ii) mercury does not wet glass (iii) mercury adheres to clean zinc or copper forming what is called an *amalgam*.

(*d*) Boil a little mercury in a test-tube and show that it is volatile. Some of the mercury condenses in tiny drops on the cool parts of the tube. Take care not to breathe any of the vapour.

(*e*) If necessary, repeat the experiment of heating red oxide of mercury (p. 262).

Mercury.—Mercury or quicksilver is the only metal which is liquid at ordinary temperatures. Its appearance is familiar to everyone from its frequent use in barometers and thermometers. It sometimes occurs pure in nature, or, as mineralogists say, *native*. Chiefly, however, it occurs in combination with sulphur as the mineral *cinnabar*, which is found in Spain, Hungary, Tuscany, and South America. If it be cooled to a temperature of −40° C. it solidifies and is then malleable. It is the heaviest liquid known, being 13½ times as heavy as water.

If it be heated to a temperature of 315° C. and air be passed over it, it combines with oxygen, forming the red oxide of mercury used in Expt. 177 to prepare oxygen. It boils at 357·25° C., and is converted into a transparent, colourless vapour, which is very poisonous. It dissolves many metals, *e.g.*, zinc and copper, forming alloys known as *amalgams.*

Not only is it used in barometers and thermometers, but also in the manufacture of looking-glasses and in the laboratory instead of water over which to collect some of the gases which are soluble in water.

Silica

EXPERIMENTAL WORK.

221. (*a*) Examine specimens of quartz, flint, siliceous sand, and as many other of the varieties of silica described in the text as you can obtain. Write down all you can about them in your note-book.

(*b*) Examine and powder some "soluble glass." Test its solubility in water. Try the action of strong acids upon it and carefully note the properties of the gelatinous silica so formed.

Crystalline Silica.—Silica is a binary compound of the elements silicon and oxygen. It is found in large quantities as more or less pure silica, as well as abundantly in combination as silicates, which are salts formed by the union of bases with silica, which acts as an acid. It is sometimes crystalline, at others amorphous. Two crystalline varieties are known, one, *tridymite*, is unimportant, while the other, *quartz*, is a frequently-occurring and highly-interesting mineral. If the quartz is quite clear and transparent, it is known as *rock-crystal*, and is the *Brazilian pebble* from which lenses are made for eye-glasses, &c. Sometimes the oxide of a heavy metal is present, colouring the quartz. If it has a purple tint, for example, it goes by the name of *amethyst*; if brown, *cairngorm*; if yellow, *citrine.*

Many *sands* are made up entirely of grains of quartz which have become more or less rounded by continual rubbing against one another in water. If the sand becomes compacted by the introduction of a cement and by the action of great pressure a *sandstone* is formed.

Amorphous Silica.—This is found in the form of (1) chalcedony and its varieties, (2) jasper and its varieties, (3) opal.

Chalcedony is known having all sorts of tints. It is often regarded as a mixture of quartz and opal; it is familiar as the well-known red stone used in signet-rings and called *carnelian. Heliotrope* is a green variety speckled with red. *Agate* is a variegated chalcedony, composed of different coloured bands.

Flint is generally of a black or dark gray colour, and is found in nodules or bands in the chalk formations of Surrey, Kent, &c. *Onyx*, *sardonyx*, *chrysoprase*, are other forms.

Jasper is an opaque, impure form of silica, of a red, brown, or yellow colour. *Egyptian* or *ribbon jasper* is a beautifully banded variety with different shades of colour.

Opal.—This species of naturally occurring silica always contains water in varying amounts. It is supposed to contain some quartz as well as amorphous silica. It is often used in jewellery; one variety shows a well-developed iridescence, and is called *precious opal.*

Common Salt

EXPERIMENTAL WORK.

222. (*a*) Make a solution of common salt in water. Evaporate some of the solution by gently heating it, and when the basin is dry examine a little of the residue. Careful inspection will discover small cubes, the shape of some of which can be recognised by the unaided eye. The cubical shape of the others can be easily made out under a magnifying glass.

(*b*) Heat some of the dry powder in a test-tube. Notice the crackling and the absence of water on the side of the tube.

Crystals of Common Salt.—Salt crystallises in six-sided solids or cubes (Fig. 223). When the crystallisation is brought about by evaporating a solution of salt, the crystals are very small. Some natural crystals, known as rock-salt, are however

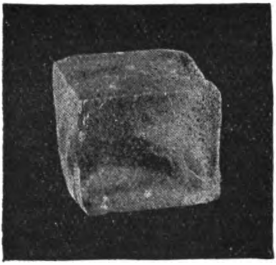


FIG. 223.—A six-sided crystal of common salt. (From a photograph by Mr. H. E. Hadley.)

of quite a large size. There is no water of crystallisation in crystals of common salt, and when they are heated no steam is given off. The crackling which is noticed when crystals of salt are heated in a tube is spoken of as **decrepitation**, and is due to the breaking-up of the crystal into fragments.

Sodium Chloride or Common Salt is found in beds of different thickness in the earth, under the name of *rock-salt.* The largest amount is found in the salt-mines of Austria. In this country rock-salt is obtained most abundantly from Cheshire. It is present in large quantities in sea-water mixed with other compounds. It is soluble in water, though one part of sodium chloride by volume requires two and a half parts of water to dissolve it, and, as is but rarely the case, warm water will dissolve no more than cold water. It is used largely to prevent decomposition of meats of all kinds. Enormous quantities are consumed in this country in the manufacture of sodium carbonate. The first stage of this process consists in acting upon the common salt with sulphuric acid, when two new compounds are formed. The first of these is a gas, hydrochloric acid gas, which when dissolved in water forms the "hydrochloric acid" used in the preparation of carbon dioxide (p. 297). The second is a white solid, sodium sulphate, known in commerce as "salt-cake."

Alkalies

EXPERIMENTAL WORK.

223 (*a*).—Place a small piece of potassium on water, and afterwards evaporate the liquid to dryness. Examine the solid produced, and compare it with caustic soda.

(*b*) Make solutions of caustic potash and caustic soda, and neutralise both by (i) sulphuric acid, (ii) nitric acid, (iii) hydrochloric acid. Carefully add dilute acid, drop by drop, until the solution will neither turn a blue litmus paper red nor a red one blue, *i.e.*, until it is neither acid nor alkaline. Evaporate the solutions so obtained and allow them to crystallise.

(*c*) Place a small piece of sodium in an evaporating dish containing water. An alkaline solution of sodium hydrate or caustic soda, which will consequently turn red litmus blue, is thus produced. Add hydrochloric acid until the solution has no effect on litmus paper. Then evaporate the solution to dryness and examine the crystals left; they will be found to be crystals of common salt. If caustic soda is dissolved in water and the solution is treated with hydrochloric acid in the same way, common salt is formed.

Acids, Bases, and Salts.—A sufficient number of elements and compounds has now been studied to make the student able to understand the meaning of these terms.

The name acid is given to those substances which have a sour taste, turn blue litmus-paper red, and cause carbon dioxide to be given off when added to a carbonate. They always contain hydrogen, which they give up when acted upon by another set of compounds, the bases. An exchange is effected. The base always contains a metal, and this metal takes the place of the hydrogen of the acid, changing the acid into a salt and the base into water.

An Acid acted upon by A Base forms A Salt and Water.

Or, to apply this general fact in a particular case,

Hydrochloric Acid uniting with Caustic Soda forms Common Salt and Water.

The bases have properties which are the reverse of those possessed by the acids. When the two come in contact, they *neutralise* one another, and the compound which results is a neutral one—it has no action upon litmus-paper. If the base is soluble in water, it is called an *alkali*. The alkalies have a soapy taste or feel, turn red litmus blue, and combine with carbon dioxide to form carbonates.

Chief Points of Chapter XX

Iron.—Occurrence: almost entirely in combination with other elements, as in magnetic iron ore (black oxide of iron), hæmatite (red oxide of iron), clay ironstone (carbonate of iron), and iron pyrites (bi-sulphide of iron). Unites with oxygen in moist air, to form iron-rust. When heated, will burn in oxygen and form black oxide of iron. Also, when heated, will unite with the oxygen of steam to form black oxide of iron, and leave the hydrogen.

Three Kinds of Iron.—(1) *Wrought-iron*, which is almost pure iron, is very tough and malleable. (2) *Cast-iron* contains carbon and silicon, and is very brittle and easily melted. (3) *Steel* contains the same elements as cast-iron, but the amount of carbon per cent. is less. It has different properties, according to the processes through which it has passed.

Mercury.—Occurrence: sometimes in the liquid form, but more commonly as Cinnabar—a compound with sulphur. Heaviest liquid known. With the exception of bromine is the only element liquid at ordinary temperatures. When heated, unites with oxygen to form mercuric oxide. Dissolves many metals to form amalgams.

Silica.—Compound of silicon and oxygen. The most abundant binary compound in the earth's crust. Occurs in crystals as quartz and tridymite, and amorphous as chalcedony, jasper, and opal. Prepared artifically, is a white, gritty powder, insoluble in water or acids.

Common Salt.—A binary compound of sodium and chlorine, and is the principal source of both these elements. Occurs as rock salt, also in brine springs, salt-lakes, and sea-water. Sometimes found in large colourless crystals of the shape of cubes.

QUESTIONS ON CHAPTER XX

1. Silver, sand, and salt are stirred up in a bottle containing water, in which carbon dioxide is dissolved. What methods would you use to recover the sand, salt, and carbon dioxide from the water?

How would you prove that the gas obtained from the water was carbon dioxide and not nitrogen?

2. Sulphuric acid and common salt are heated in a flask.

What substances will be produced?

How would you arrange for the experiment?

3. Name the elements of which water, common salt, and lime are composed, and state what you know about the elements in question.

4. (*a*) What is the most abundant oxide in the earth's crust, and of what elements is it composed?

(*b*) State what you know about the properties of this oxide.

(*c*) Name the crystalline form of this oxide.

(*a*) Name three rocks in which this oxide is found in its crystalline form.

5. What experiments would you perform before a class to demonstrate the chief properties of mercury? Name some uses of this element.

6. Enumerate the chief kinds of iron. State the chief properties of each, and give some useful application of each characteristic you name.

7. Explain carefully the meaning of the terms (*a*) alkaline substance, (*b*) acid substance. What happens exactly when a dilute solution of sulphuric acid is gradually added to one of sodium hydrate?

8. What chemical action takes place when a small piece of metallic sodium is thrown into water?

How would you test whether the solution left is acid or alkaline, and how would you prepare from it some common salt in the crystalline state?

CHAPTER XXI

TERRESTRIAL MAGNETISM.

Natural and Artificial Magnets

EXPERIMENTAL WORK.

224. *Lodestone is a Natural Magnet.*—Examine a piece of lodestone. Dip it into iron filings. Observe that the filings adhere in tufts to certain parts of the lodestone.

225. *Directive Character.*—Take a second piece of lodestone which has been roughly shaped so that the places where the filings adhered are now situated near its ends. Support the piece of lodestone in a stirrup as shown in Fig. 224, and prove that even if at first

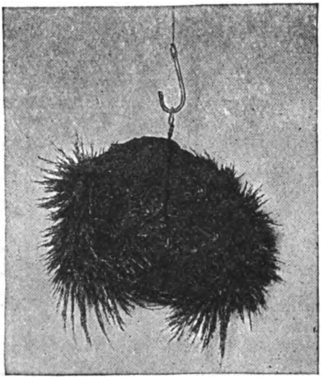


Fig. 224.—Iron filings attracted by a lodestone.

arranged in any other way, the piece of lodestone, after swinging about for some time, eventually *comes to rest along a certain line, and one end of the lodestone, which you can mark with chalk, always points in the same direction.*

226. *Action between two Lodestones.*—Leave the piece of lodestone of the last exercise suspended in its position of rest. Bring up the first piece of lodestone towards it in such a manner that one of the places where the filings adhered points at the end of the suspended piece. Observe what happens. Now point it at the other end of the suspended lodestone and again observe the result.

In one case *attraction* takes place, while in the other *repulsion* ensues.

227. *To make a Magnet.*—Take a good sized sewing needle and fix it on the table with a little soft wax. Using the piece of lodestone from the stirrup in the last experiment, and beginning at the point of the needle, rub the end of the lodestone along the length of the needle, and when you get to the eye, raise the lodestone and bring it again on to the point of the needle and repeat the stroking process. Do this 10 or 12 times.

228. *Properties of a Magnet.*—Examine the needle. It will now attract iron filings at its ends. Support it in a tiny stirrup (Fig. 225), and see that it arranges itself as the shaped piece of lodestone did. Also notice that while the point is either attracted or repelled by the end of the shaped lodestone, the eye is repelled or attracted, that is behaves in an exactly opposite manner.

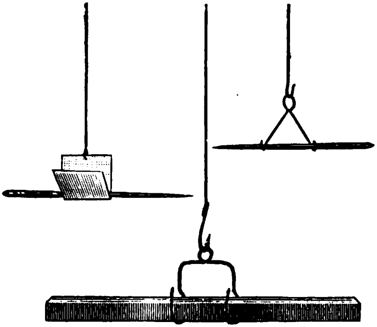


FIG. 225.—Magnets supported in stirrups.

The needle has been made into a *magnet*, or has become *magnetised.* Most filings are attracted at its ends, or, as we say, the *poles of* the magnet are at its ends.

229. *Artificial Magnets.*—Examine several forms of *artificial magnets.* Notice that some are in the shape of *bars*, others in that of a *horse-shoe.*

Treat the bar magnet in the same way as the shaped lodestone, thus:

(*a*) Support in a stirrup (Fig. 226), and see that it arranges itself along the *same* line as the lodestone.

(*b*) Dip both ends successively into iron filings. Notice and sketch the way in which the filings form a tuft. These ends are the poles. No filings adhere to the centre of the magnet.

(*c*) Support the magnetised needle as in Fig. 226. Bring first one end of the bar magnet, and then the other, up to the point of the needle. Notice and record the result. Repeat, using the eye of the needle.

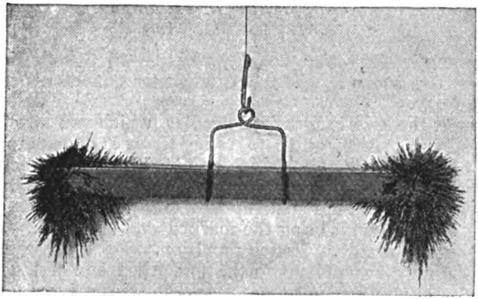


FIG. 226.—Iron filings attracted by a suspended magnet.

In every respect the artificial magnet has the same magnetic properties as the lodestone.

Lodestone.—It has already been pointed out that lodestone is a binary compound of iron and oxygen (p. 305) which occurs in the earth's crust. It is more commonly known as *magnetite* (p. 303). The name lodestone is reserved for those varieties which have magnetic properties; the name itself means "leading-stone" and refers to its early use for navigating ships. This mineral is found in considerable quantities in Scandinavia, Asia Minor, United States, and other places. Its appearance has already been referred to.

Artificial Magnets.—The experiments already described teach several important facts. Lodestone is naturally able to attract iron-filings. It naturally arranges itself in a particular way when allowed to hang freely. It can impart these properties to pieces of steel, converting them into artificial magnets. These, in their turn, can make other pieces of steel into artificial magnets. All artificial magnets arrange themselves in the same way when freely suspended.

Primary Laws of Magnetism

EXPERIMENTAL WORK.

230. *Magnetic Attraction and Repulsion.*—(*a*) Substituting the bar magnet for the shaped lodestone, magnetise another needle as in Experiment 227.

(*b*) Support the two magnetised needles, which you now have, each in a little stirrup. Allow them to swing freely and come to rest. On the ends of the two needles which point in the same direction stick a piece of paper, or mark them in some other convenient way.

(*c*) Leave one needle in its stirrup and take the other out. Holding the needle in your hand, bring the marked end up to the marked end of the suspended needle. Notice repulsion. Bring the unmarked end of the needle in your hand up to the unmarked end of the suspended needle. Again notice repulsion.

(*d*) Now bring the unmarked end of one against the marked end of the other. Notice attraction.

(*e*) Substitute a soft-iron nail for the needle in your hand in the last experiment. Notice that when either end of the nail is brought up to the marked or unmarked end of the suspended magnetised needle attraction ensues.

Since unmagnetised iron will attract both poles of a magnetic needle, we are led to an important conclusion, viz. that *repulsion is the only sure test of permanent magnetisation.*

231. *Action between Poles of Magnet and Compass Needle.*—(*a*) Procure an ordinary compass needle, which is simply a light magnetic needle suspended as in Fig. 227, so that it can move easily in a horizontal plane. Notice that one end, which is marked, always points towards the north, and is called the *north-seeking* end. Bring up towards this marked end of the compass needle that end of a bar-magnet which points to the north, when it is freely suspended in a stirrup, and which is marked with an N. Notice that they *repel* one another. Repeat the experiment using the unmarked, or *south-seeking*, end of the needle and bar-magnet. Observe they similarly *repel* one another.

(*b*) Repeat the last experiment, only make the unmarked end of the bar-magnet approach the marked end of the needle. Observe that they rush together or *attract* one another. Similarly, notice that unlike poles in all circumstances attract one another (Fig. 227.)

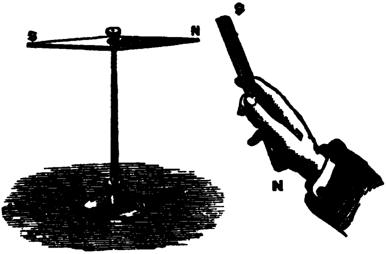


FIG. 227.—Magnetic Attraction.

232. Place a bar-magnet upon the table. Arrange a compass needle upon it so that its point of suspension is on the neutral line of the magnet. Set the compass needle swinging and then allow it to come to rest. Observe that the needle arranges itself, with its marked end pointing towards the unmarked end of the magnet. The reverse is true of the other pole of the needle.

We say the magnet exerts a *directive* force upon the needle. Put the needle in other positions on the magnet and notice the same fact.

233. *Result of Breaking a Magnet.*—(*a*) Magnetise a piece of clock-spring. Find which end is repelled by the marked end of a suspended magnetic needle, and stick a piece of paper on this end. Convince yourself that the other end of the piece of hardened spring is attracted by the marked end of the suspended needle. Observe, too, that the middle of the piece of spring has no effect on the needle.

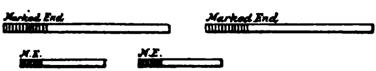


FIG. 228.—Effect of breaking a magnet.

(*b*) Break the piece of spring into halves, and examine each piece by bringing the ends of the pieces in turn up to the suspended needle. What was, before breaking, the middle part of the piece of spring is now found to affect the needle and to attract the iron filings. Each piece has thus become a perfect magnet.

(*c*) By means of the suspended magnetised needle satisfy yourself that the other end of the half, which is marked, is attracted by the marked end of the needle, and that the other end of the half, which is unmarked, repels the marked end of the needle.

(*d*) Break one half into two equal parts. Show in the way used in the last experiment that each part is a perfect magnet. Also find how the poles are arranged. Record your results, and compare them with Fig. 228.

(*e*) Very nearly fill a small narrow test-tube with *steel* (not iron) filings, and close the tube with a well-fitting cork. By the method already learnt, and using a large, strong magnet, magnetise the tube and its contents as if it were a bar of iron. Satisfy yourself that you have magnetised it, by observing its action on a magnetic needle. Now shake the filings out of the tube on to a sheet of paper; toss them about, and then replace them in the tube, and again test its magnetic condition with a magnetic needle. The tube and its contents no longer behave as a magnet.

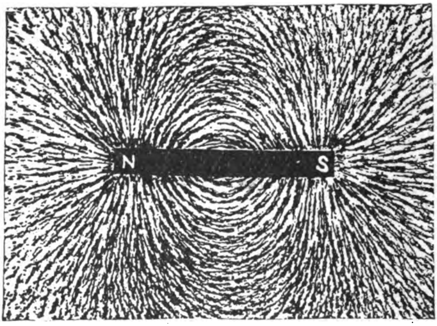


FIG. 229.—Lines of force of a single bar magnet.

234. *Lines of Force.*—Place a bar magnet on the table, and over it place a thin sheet of cardboard. Sprinkle fine iron filings on to the card, either from a fine pepper castor or from a fine muslin bag. Gently tap the sheet of cardboard, when the filings will be seen to arrange themselves along definite lines, which are called *Lines of Force* (Fig. 229).

(*b*) Substitute a sheet of glass for the cardboard, and repeat the experiment. Make in your note-book a sketch of the figure obtained.

(*c*) Similarly obtain the lines of force for a horse-shoe magnet, and for the following combinations.

(i) Two bar magnets in the same straight line, with opposite poles an inch apart.

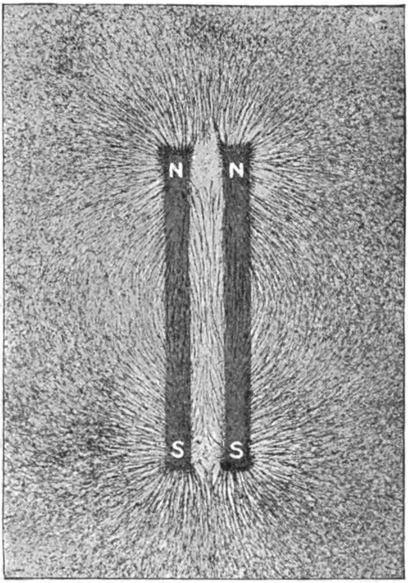


FIG. 230.—Lines of force of two bar magnets with like poles adjacent.

(ii) Same arrangement, only similar poles, an inch apart.

(iii) Two bar magnets arranged parallel with similar poles near one another (Fig. 230).

(iv) Two bar magnets arranged parallel with opposite poles near one another (Fig. 231).

(v) One pole of a bar magnet held vertically under the piece of cardboard.

Experiments like those just described teach the rule referred to as the *First Law of Magnetic Attraction and Repulsion*, which can be stated thus :—

Like magnetic poles repel one another.
Unlike magnetic poles attract one another.

It must, however, be noticed here that, although repulsion is sufficient proof that two like poles are acting upon one another, attraction is not necessarily due to the mutual action of two unlike poles, since as has been seen in Exp. 230 (*e*), magnets can attract unmagnetised iron which has no poles at all.

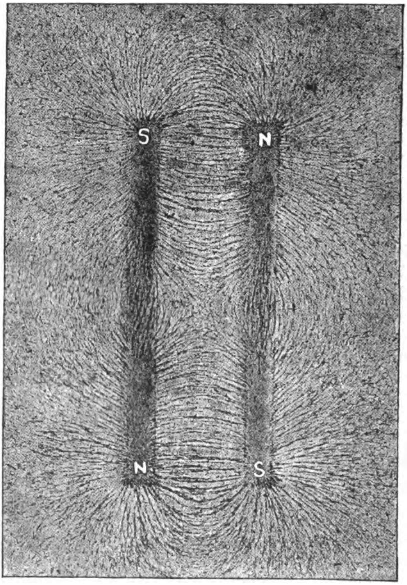


FIG. 231.—Lines of force of two bar magnets with unlike poles adjacent.

Why a Magnetic needle points to the North.—A compass needle always arranges itself with its marked or N end towards the magnetic north, because the earth acts like a bar-magnet. The line in which the needle arranges itself is called the *magnetic meridian.* A certain part of the earth in the northern hemisphere acts like the unmarked or south-seeking end of the magnet, and attracts the marked end of the needle. The place where this attractive force is greatest is called the *north magnetic pole*, and though at first it seems contradictory, there must evidently be the south-seeking kind of magnetism at the north magnetic pole. The student must avoid the common error of believing that the south pole of a magnet points towards the north. The *north* pole of a magnet points towards the north; and the question as to the kind of magnetism at the earth's magnetic poles does not affect the names given to the poles of a compass or magnet.

Lines of Force.—When a bar magnet is covered with a sheet of card or glass, and iron filings are sprinkled on the card, if the card is tapped the filings arrange themselves along definite lines. The filings chiefly collect round the ends, which contain the *poles* of the magnet. The poles are placed near the ends of the bar-magnet, where the magnetic power is most strongly shown. A line joining the poles is called the *magnetic axis.* A line at right angles to the axis and midway between the poles is known as the *neutral line or magnetic equator.* It has been seen that there are no filings along this line, where the opposite magnetic properties appear to neutralise one another.

When two magnets are placed near one another the lines of force due to them can be shown by means of iron filings, the curves in which the filings arrange themselves indicate the direction of the magnetic force.

Magnetic Declination

EXPERIMENTAL WORK.

235. *Magnetic Meridian.*—(*a*) Remove all magnets, also any masses of iron, to a distance. Support a bar magnet in a stirrup, and see that it swings freely (Fig. 225). Allow it to come to rest and then draw a chalk line on the table, marking the line along which the magnet arranges itself. One way of doing this is to make marks on the table immediately below the middle points of both ends of the magnet by the help of a plumb line, and then to join the marks by means of a straight edge. Or, you may draw a line accurately parallel to one of the long sides of the magnet. But the best plan is to fix two needles vertically at the ends of the magnet as in Fig. 232, and draw a line between

them. Then turn the magnet over, so that the top becomes the bottom, and draw another line. The mean position between the two lines thus drawn is the magnetic meridian.

(*b*) Freely support each of the magnets you have in order, viz. the shaped lodestone, the magnetised needles, and the horse-shoe magnet above this line. The horse-shoe magnet is best supported vertically by a thread. Notice that on coming to rest they all arrange themselves along it.

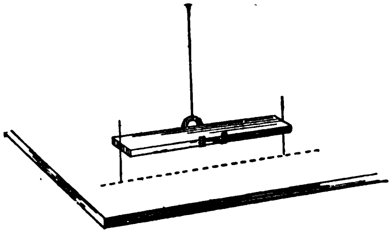


FIG. 232.—Determination of magnetic meridian.

The line along which a freely suspended magnet arranges itself is known as the magnetic meridian, and it can be at once *roughly* traced for any place by the simple experiments you have performed.

236. *How to find the Geographical Meridian.*—Allow a freely-suspended compass needle to come to rest. Draw a line on the table marking out the direction of the needle. Through the point under the spot where the needle is supported draw a line inclined to the *magnetic meridian* you have just drawn at an angle equal to the magnetic declination of the place, which is marked on Fig. 240. The line thus obtained is the geographical meridian.

Declination, or Variation.—The magnetic poles of the earth do not coincide with its geographical poles (Fig. 233). You will see, as the chapter proceeds, how the former are located. Great circles round the earth, which pass through the geographical poles, are known as the meridians of longitude; and a line drawn in a true north and south direction at any place is the meridian of that place. Similarly, the direction in which a compass needle arranges itself at any place may be called the *magnetic meridian* of that place. Only in a few parts of the earth does a magnetic north and south line lie in exactly the same direction as true north and south; usually the geographical and magnetic meridians intersect one another at

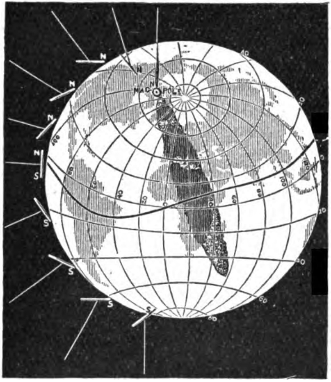


FIG. 233.—Magnetic and geographical meridians and poles.

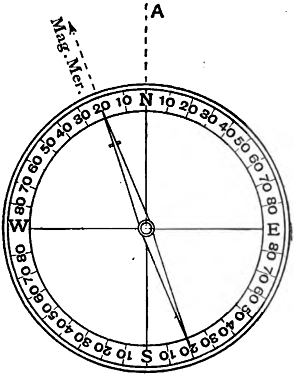


FIG. 234.—Magnetic declination.

an angle which varies in amount from place to place on the earth's surface. *The angle between the geographical and magnetic meridians of any place is called the declination or variation of that place* (Fig. 233). Its value for any year at various places is recorded in the *Nautical Almanac* and other publications. At Greenwich Observatory in 1904 the declination was 16° 19′. Having a compass needle and knowing the angle of declination it is easy to determine the geographical meridian through a place. The direction in which the compass sets itself is found, and then allowance is made east or west of this according to the declination of the place of observation.

Dip.

EXPERIMENTAL WORK.

237. *Magnetic Dip.*—Take a knitting needle and support it by a fibre or two of unspun silk, attached by soft wax, so that it arranges itself horizontally. Now, holding it carefully so as not to break the silk,

magnetise it by the method of single touch. Allow it to again hang freely. It is no longer horizontal. One end *dips* down. By means of a compass needle ascertain which pole is dipping, and record your result.

238. *The Dipping Needle.*—A needle which is free to move on a vertical plane, but fixed as regards movement in a horizontal plane, is called a dipping needle. Either use the dipping needle provided, or make a simple form yourself. This may be done as follows:—

Select an unmagnetised knitting-needle about 6 ins. long. Construct an axle for the needle in the following manner:—Hold two short pieces of copper wire on opposite sides of and at right angles to the length of the needle. Twist the ends of the wires together on each side so as to grip the needle tightly, and carefully straighten the twists. Make the wire surfaces as smooth as possible by heating in a gas-flame and applying sealing-wax, shaking off the excess of wax while still fluid (Fig. 235). Apply a spot of sealing-wax so as to rigidly connect the axle to the needle. Make a support for the needle by cutting two rectangular pieces of sheet brass or copper (3 ins. × ½ in.), rigidly connect them together at the base with their short edges horizontal and ½ in. apart, and fix them to a suitable base-board. Attach a circular scale of 90° to one of the supports (Fig. 236). See whether the needle

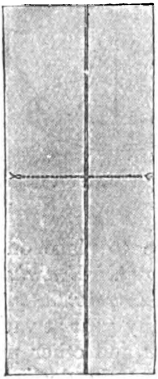


FIG. 235.—Method of supporting a simple dipping needle.

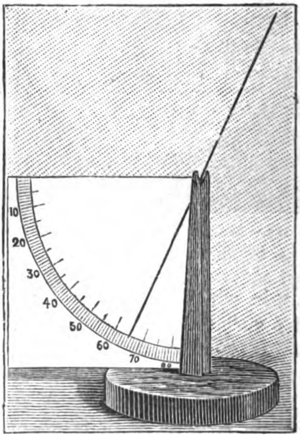


FIG. 236.—Simple form of dipping needle, due to Mr. H. E. Hadley.

is truly balanced by supporting it by its axle on the knife edges; if necessary, adjust the position of the axle by slightly warming the sealing wax joint and moving the axle along the needle. Carefully magnetise the needle. Place it on the knife-edges with its axle coinciding with the centre of the circular scale.

239. *Determination of the Angle of Dip.*—(*a*) To make an accurate measurement of this angle you must be sure of one or two things. *The needle must move in the plane of the magnetic meridian.* One plan to ensure this is as follows: Carefully draw the magnetic meridian by Expt. 235 (*a*) and then arrange the needle parallel to this line. By this means, when the needle moves it is always in the plane of the meridian.

(*b*) A better way, and the plan generally adopted, is first to rotate the needle until it stands quite vertical. Then turn the plane in which the needle is free to move through exactly 90°, thus making this plane to coincide exactly with the magnetic meridian, and observe the angle by which one end of the needle dips below the horizontal position.

240. *Explanation of Angle of Dip.*—Magnetise a sewing needle as in Expt. 227. Suspend it by a thread so that it hangs quite horizontally. Bring it over the neutral line of a bar-magnet and notice that it remains horizontal. Gradually move it towards the north-seeking end of the magnet. Observe that as the pole of the magnet is approached the south-seeking end of the needle becomes inclined at larger and larger angles to the bar-magnet, until when it is over the end it is vertical. The angle which the needle makes with the bar-magnet corresponds to the *angle of dip of a dipping needle.*

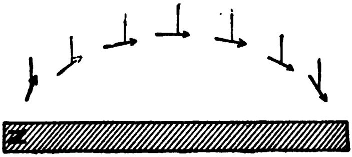


FIG. 237.—Experiment to illustrate the cause of magnetic dip.

A Dipping Needle.—Is simply a magnetic needle suspended in such a manner that it is free to move in a vertical plane in a manner similar to that in which the magnetised knitting needle moves in the Experiment 237 (*a*). Fig. 238 will make the principle of its construction clear.

A good form of this instrument is shown in Fig. 239. A magnetic needle, supported in a horizontal plane, is free to move vertically round a graduated circle. This circle is attached to a framework, which is carefully centered and so arranged that it can rotate about a vertical axis which passes through the centre of suspension of the needle. The centre of suspension should moreover be at the centre of gravity of the needle.

When measuring the angle of dip at a place with such an instrument, the framework is slowly rotated until the needle stands vertical. When this condition of things obtains the plane of the needle is at right angles to the magnetic meridian. The framework is consequently rotated through 90 degrees in order to bring it into the plane of the magnetic meridian, and the angle which the needle makes with the horizon in this latter position is an exact measure of the angle of dip at the place of observation. There are several important adjustments to obviate any error in the suspension of the needle which the interested student will find explained in books on Magnetism.

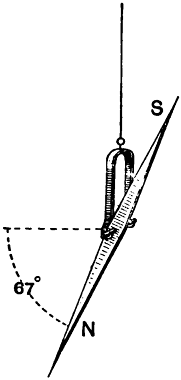


FIG. 238.—Angle of dip at Greenwich.

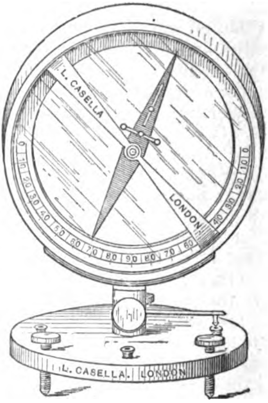
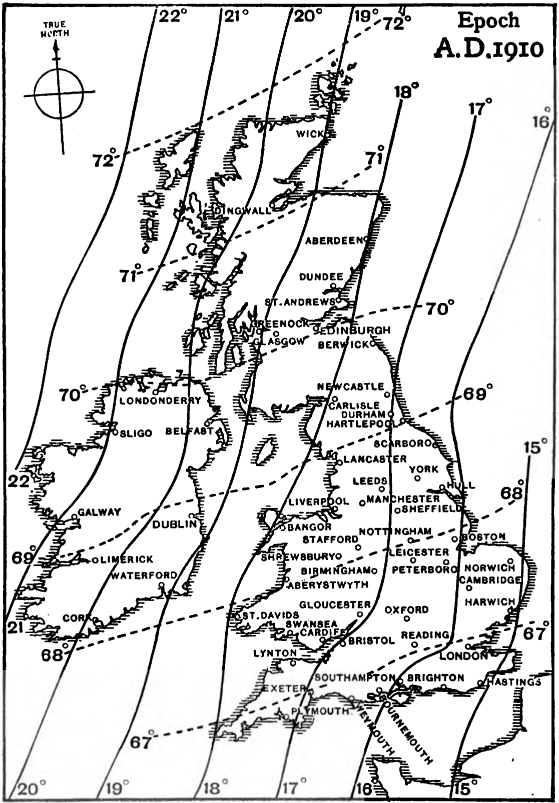


FIG. 239.—Student's dipping needle.

The *dip circles* which are used for measuring inclination in such magnetic observatories as that of Kew are much more elaborate and delicate instruments, but the principles of their construction and action are identical. The value of the magnetic declination and dip in different parts of the British Isles are shown in Fig. 240.



Emery Walker sc.

FIG. 240.—Magnetic Chart of the British Isles, showing the lines of equal declination and those of equal magnetic dip. (From *Elementary Lessons in Electricity and Magnetism*, by Prof. S. P. Thompson.)

Behaviour of the Dipping Needle at different Places on the Earth's Surface.—It is seen that the needle assumes a horizontal position when above the neutral line, or magnetic equator of the magnet. When above the poles of the magnet the needle stands vertical, and in intermediate positions the needle is inclined at a greater and greater angle as the pole is approached. Moreover, over the north-seeking end of the bar magnet the south-seeking pole of the needle is below, whereas over the other end of the bar magnet the north-seeking pole of the needle is in the lowest position (Fig. 237).

Precisely the same thing is observed in the case of the earth; in some places the dipping needle adopts a horizontal position, and a line joining in all those stations where this is so marks out the *magnetic equator of the earth.* When the needle is moved away from this equator towards one of the magnetic poles of the earth, the dipping needle makes a larger and larger angle with the horizon, or, what is the same thing, the angle of dip increases, until eventually the needle stands vertical or the angle of dip is a maximum. When this is so we know that one of the magnetic poles of the earth has been reached.

Position of the Earth's Magnetic Poles.—The magnetic poles of the earth, which are located by the vertical position of the dipping needle in their immediate neighbourhood, do not coincide with the geographical poles. The north magnetic pole, at which there must be south-seeking magnetism, because the north-seeking pole of the dipping needle is the one which dips, is situated a thousand miles away from the north geographical pole at Boothia Felix in lat. 70° 5′ N., and long. 96° 46′ W. Its position was discovered by Sir James Ross in 1831. The south magnetic pole has not yet been reached; but Ross found that the angle of dip in the position lat. 76° S. and long. 168° E., was 88° 37′, and it has been calculated from his observations that the south magnetic pole is located about lat. 75½° S. and long. 154° E. There is, moreover, every reason to suppose that there are two south magnetic poles.

The Earth as a Magnet.—The various phenomena, to which we have only been able to refer briefly, would all happen in precisely the same way if passing through the earth there were a huge bar-magnet arranged along a diameter with its south-seeking pole under the north magnetic pole. The position given by the dipping needle is exactly that which such a bar-magnet would make it take up. The neutral line of the bar-magnet would be the position of the magnetic equator of the earth, and the magnetic poles of the earth would be over those of the magnet. Of course, we know very well that no such gigantic magnet is hidden away in the earth's interior, but the illustration affords a ready means of remembering the chief points which have been enumerated.

The Mariner's Compass.—Expt. 235 (*b*) has shown that every suitably supported magnet arranges itself in the magnetic meridian, and it is on this fact that the mariner's compass depends for its construction. In the actual instrument, a flat needle is suspended by means of an agate cap, placed at its centre of gravity. The cap works on a point in such a manner that the needle can move freely in a horizontal plane. On the top of the needle a card, divided as shown in Fig. 241, is fixed, care being taken that the centre of the needle is under the

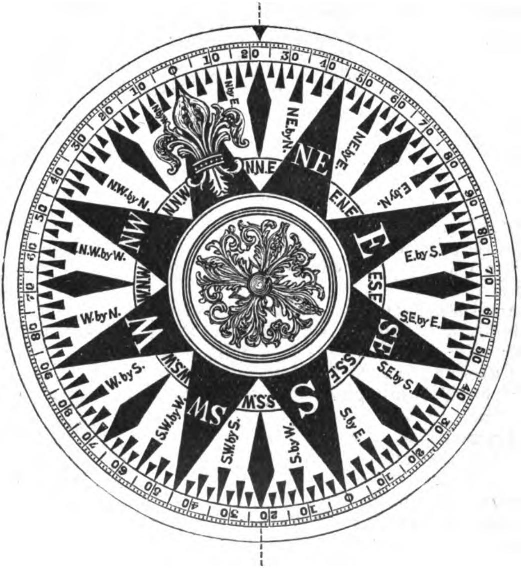


FIG. 241.—The Mariner's Compass.

centre of the card, and the north-seeking pole of the magnet under the division marked north on the card. This north point is indicated in the figure by means of the *fleur-de-lis*. With this arrangement the direction of the magnetic north pole is always seen by looking at the *fleur-de-lis*. The dotted line indicates the direction of the middle line, from bow to stern, of the ship upon which the compass-card in the figure is supposed to be. When the man at the helm wishes the ship to travel in any particular direction, he turns the wheel until the required point of the compass comes under the arrow on the dotted line. In Fig. 241 the compass-card indicates that the ship, the medial line of which is shown, is travelling in a N.N.E. direction.

CHIEF POINTS OF CHAPTER XXI

Lodestone is a natural binary compound of iron and oxygen which possesses the property (1) of attracting iron and steel filings; (2) of coming to rest in a *magnetic* north and south line when freely suspended or balanced.

Artificial Magnets have the same properties as lodestone; they can be made (1) by stroking a piece of steel in one direction with a lodestone or with a magnet; (2) by coiling a silk-covered wire around a piece of steel and passing a current of electricity through it.

In every respect artificial magnets have the same magnetic properties as lodestone.

The Primary Law of magnetic attraction and repulsion is, like poles repel one another; unlike poles attract one another.

When a magnet is broken each of the resulting parts is a magnet possessing both a north- and south-seeking pole.

Magnetic Declination or Variation is the angle between a true north and south line (shown by a noonday shadow) and a magnetic north and south line (shown by a compass needle). It differs at different places.

Magnetic Dip or Inclination is the angle which a magnetic needle turning about a horizontal axis makes with the horizon when the vertical plane in which it moves coincides with the magnetic meridian.

A **Dipping Needle** simply consists of a magnet supported on a horizontal axle and free to move in a vertical plane. The needle must swing exactly in the magnetic meridian before the angle of dip at a place is measured.

The Earth's Magnetic Poles are the points through which magnetic meridians pass, and at which a dipping needle would set vertically. The north magnetic pole is in Boothia Felix, but the south magnetic pole has not been reached.

QUESTIONS ON CHAPTER XXI

1. A magnetic needle balances so that it is free to turn in any direction, either upwards or sideways. How will it settle? The experiment is performed in England.

2. Suppose you are given a small compass and two knitting needles, of which one is slightly magnetised and the other unmagnetised. How will you find (1) which needle is which, and (2) which is the North seeking end of the magnetised needle?

3. A bar magnet is broken into four pieces. What magnetism do these pieces possess? How can you prove the truth of your answer?

4. Two compasses are put near together on a table. In what positions may the needles be expected not to disturb one another? How will the needles behave when one compass is put to the magnetic North West of the other?

5. A magnet is imbedded in a piece of wood. How can the position in which it lies be determined without breaking the wood?

How could you determine the magnetic north and south direction by means of such a hidden magnet?

6. Explain the meaning of the following:—

(*a*) The mean declination at Greenwich in 1896 was 16° 56′·5 west.

(*b*) The mean dip at Greenwich in 1896 was 67° 9′. State why it is necessary to specify the place and the year in which the observations were made.

7. If you were provided with a small magnetic needle upon a pivot, and also with two bar magnets, how would you determine (*a*) which is the north pole of the needle; (*b*) which is the north end of each of the magnets; (*c*) whether the two magnets are of equal strength or not?

8. Describe how a "dipping needle" may be used to determine the magnetic meridian at a place.

What differences would be observed in the position in which a "dipping needle" comes to rest when free to turn in the magnetic meridian (*a*) at the earth's magnetic poles; (*b*) at the magnetic equator; (*c*) at a place in the British Isles?

9. What is the "dip" of a magnetic needle? Why is it greatest at the magnetic poles?

10. Describe the mariner's compass and its chief uses.

11. Describe the behaviour of a magnetic needle mounted on a horizontal axis in the neighbourhood of London. State what would happen if it were carried—

(*a*) Towards the equator.

(*b*) Towards the north pole.

12. Describe an experiment by which the laws of attraction and repulsion by magnets can be easily demonstrated.

MISCELLANEOUS QUESTIONS FROM EXAMINATION PAPERS

A. General Properties of Matter.

1. A rectangular cistern has to be constructed to hold 500 litres, and the area of the base of the cistern is to be 40 square decimetres. What must be the depth of the cistern in metres?

If the cistern is filled to a depth of 50 centimetres with a liquid of specific gravity 1·5, what will be the weight of liquid in the cistern?

2. Seven posts alongside a railway are placed at equal distances of 100 feet from each other, and a passenger in a passing train notices that he passes these posts at the following times, 2·0, 7·0, 11·5, 15·5, 19·0, 22·5, 26·0 seconds. Is the speed of the train uniform throughout? Calculate the speed, and if not uniform, the acceleration with which the train is moving.

3. Two men have to carry a weight of 1 cwt. slung on a pole 12 feet long, each man supporting one end of the pole. If one of the men is twice as strong as the other, where must the weight be slung on the pole that each man may have to carry his fair share of the load?

4. Explain why it is that a mop can be dried by twirling it round. Describe some experiment which you would perform to illustrate the correctness of your explanation.

5. Describe an experiment to show that when water is converted into steam there is no loss of weight.

6. How do you explain the fact that while a soap-bubble filled with air is attracted, a similar bubble filled with hydrogen is apparently repelled by the earth?

7. A boatman on one side of a river wishes to reach a point directly opposite. Draw a diagram to show in what direction he must row. Will the distance he rows be the same as it would be if there were no current?

8. Show how the principle of the lever is illustrated by (1) a crowbar, (2) a pair of scissors, (3) a pair of tongs.

9. What is meant by a unit of length? What is the unit of length

in the metric system, and how is it subdivided? How many centimetres are there in a foot?

10. What is meant by the specific gravity of a body?

A lump of iron weighs in air 10 kilograms, and is known to contain a cavity filled with air. When weighed in water its apparent weight is 8·46 kilograms. If the specific gravity of iron is 7, what is the volume of the cavity in the iron?

11. What is meant by the resultant of two forces?

Draw a diagram to scale showing the resultant of two forces acting at a point, one of them being a force of 4 kilos acting from north to south, and the other a force of 1 kilo acting from south-east to north-west.

12. What is meant by energy?

What experiments would you make to prove that a moving body possesses energy owing to its motion?

13. What is the connection between the units of length and mass in the metric system?

Give the approximate equivalents in ordinary English units of 35 centimetres, 3 kilometres, 5 kilograms, 4 litres.

14. Explain the term *specific gravity*. What is the law of Archimedes? If the stopper of a bottle weighs 15·5 gr. in air, 9·3 gr. in water, and 10·1 gr. in turpentine, what are the specific gravities of glass and turpentine?

15. A pendulum consists of a bullet attached to a fine string. When the bullet is drawn on one side and let go, why does not the bullet stop when the string reaches the vertical position? What forces act upon the bullet at the beginning, middle, and end of its swing?

16. In the last question, what changes, if any, in the energy of the bullet take place during a complete swing of the pendulum?

17. A simple pendulum consisting of a metal ball attached to a fine string is in vibration. What will be the motion of the ball if the string is cut (1) at the beginning or end of a swing, (2) in the middle of a swing?

18. What do you understand by the parallelogram of forces? Show how it is illustrated in the case in which three dogs are pulling at a bone in different directions with such forces that the bone does not move.

19. A cube of glass, 4 cm. along each edge, when fastened to a string and weighed in water weighs 96 grams. What is the specific gravity of the glass?

20. What properties have gases, liquids, and solids in common? Mention some properties (say three) in which a liquid differs from a solid.

21. What is the unit of volume in (*a*) the metric system and (*b*) the British system of units?

Is there in either case any simple relation between the unit of volume and the units of mass or length? If so, explain these relations and describe any advantages which such relations give.

22. The volume of a submarine boat is 4·5 cubic metres, and the

weight of the hull and its contents is 4,150 kilograms. What volume of water will have to be taken into the boat so that it may just be able to sink?

23. Explain how the unit of time, the hour, is derived.

What will be the longitude of a place such that noon occurs there six hours after noon at Greenwich?

24. Explain why it is that if a bucket containing water is slowly turned over the water escapes, but if the bucket is whirled round quickly no water escapes.

25. An iron bar is bent into the shape of a capital L. It is suspended by a thread fastened to one end of the bar. Draw a diagram to show the position in which the bar will hang, and give any explanation you think necessary.

26. An egg sinks to the bottom of a vessel of fresh water. Salt is gradually added to the water. What results may be observed? How do you account for these results?

27. A boy standing in a moving cart throws a stone. In which direction can he throw farthest? In which direction least far? How must he aim if he wishes to hit a post which the cart is passing? Give any explanation you think necessary.

28. Draw a sketch of any barometer you have seen. Why do we use mercury in the instrument? What objections would attach to the use of water?

29. A wooden penholder is eight inches long and tapers off at one end. It can be balanced upon the back of a knife if the knife is placed at a distance of three inches from the thick end. When a weight of 2 grams is fastened to its thin end, the penholder balances if the knife-edge is placed under its middle point. What is the weight of the penholder? Explain how you obtain your answer.

B. HEAT AND LIGHT.

1. When the stopper sticks in a glass bottle it can often be loosened by rapidly warming the neck of the bottle. Why is this? Why is it that if the neck of the bottle be warmed very slowly the stopper is not loosened, while, on the other hand, if the warming is too rapid the bottle breaks?

2. Describe two experiments to illustrate the change in volume which occurs when water freezes. What influence has this change in volume on the freezing of ponds and lakes in temperate regions?

3. What are the laws of reflection? If you were given a piece of cardboard on which are ruled two straight lines which meet at a point, a small mirror which can stand with its reflecting surface at right angles to the cardboard, some pins and a ruler, explain how, by means of this apparatus, you could draw a line to bisect the angle between the two given lines on the card.

4. The only light in a room is supplied by a Bunsen flame in which

is suspended a small bead of common salt, and pieces of card painted with the following colours, black, red, yellow, green, blue, white, and grey respectively, are held near the light. Describe and explain the appearance of the different cards.

5. When the attempt is made to boil eggs at the top of a high mountain it is found that if the eggs are immersed in boiling water for the same time as is required to cook them at the sea-level, they are not equally cooked. Explain carefully the reason for this failure, and suggest some method by which the difficulty might be overcome.

6. How would you prove that air is heated when compressed, and cooled when expanded?

7. A clock with a metal pendulum keeps good time in the winter, but loses time in the summer. How do you explain this?

8. The temperature of the air in a room which had been shut up for some time was found to fall when warm water was sprinkled on the floor. How would you explain this observation?

9. How would you construct a pinhole camera? Give a diagram of the apparatus showing the nature and size of the image of a small object placed in front of it.

10. A vertical bar of a window, when viewed through a prism with its edge vertical, appears red on one side and blue on the other. Explain this.

11. Two exactly similar copper vessels are each half filled with water. The water in one vessel has a temperature of 0° C. and that in the other a temperature of 100° C. Explain why it is that if the cold water is poured into the vessel containing the hot water the resulting temperature is above 50°, while if the hot water is poured into the cold, the resulting temperature is below 50°.

12. What is meant by change of state?

Name an example of some substance which you know in two states, and give the conditions under which this substance can exist (1) in one of the states, (2) in the other, and (3) partly in one and partly in the other.

13. What is meant by the refraction of light?

Draw very carefully a diagram showing the passage of a ray of light through a slab of glass with parallel sides, the angle of incidence on the first surface being about 60°, *i.e.*, rather *greater* than half a right angle.

14. Explain, giving a diagram, what is meant by saying that the angle of reflection is equal to the angle of incidence.

If you were given a knitting needle with a little soft wax at one end, how would you adjust the needle so as to be perpendicular to the surface of a mirror?

15. Three similar beakers containing equal weights of water, turpentine, and mercury, all at the same temperature, are placed at equal distances in front of a fire. Would you expect them to be all at the same temperature at the end of half an hour? If not, why not?

16. A pound of ice-cold water is heated to 50° C. by the addition to

it of one pound of boiling water; also it is found that less than an ounce and a half of steam, at the same temperature as the boiling water, is capable of heating the cold water to the same extent. How do you explain this?

17. If you look at a tall post through a small piece of thick plate-glass, the part of the post seen through the glass seems, in most positions of the glass, to be detached from the rest. How do you account for this?

18. Explain how you would hold a glass prism with its edge horizontal, so as to be able to see through it a horizontal window bar. How would the appearance of the window bar, so seen, be altered?

19. Given an empty thermometer, explain how you would fill it with mercury and determine on it the fixed points corresponding to 0° and 100° C.

20. Distinguish between conduction and convection of heat, and state what experiments you would make to exhibit the distinction.

21. Show clearly how you would, by means of pins, trace out the course of a ray of light through a thick plate of glass.

22. What is a spectrum? Describe and explain the appearance of a strip of cardboard which has been painted bright red, when held so that the colours of the spectrum fall upon it.

23. A wide flat dish containing water is heated over a lamp, and although after a time a considerable amount of steam rises the water never actually boils. On placing a cover, however, over the dish the water soon begins to boil. Why is this?

24. What is meant by convection? Apply your explanation to account for the fact that a chimney "draws."

25. Explain, illustrating your answer by a diagram, how you would trace the course of a ray of light through a thick plate of glass.

26. Explain, giving a diagram, why a pebble seen at the bottom of a pond appears nearer the surface than it is really. In your diagram the directions in which the light rays are proceeding must be indicated.

27. Water, alcohol, and mercury are heated from a temperature of 1° Centigrade to a temperature of 20° Centigrade. How can you prove that these liquids expand at unequal rates?

28. The glass stopper of a glass bottle is found to be jammed. Describe some method by which it may be extracted. Explain the principle on which your method is founded.

29. Describe and explain an experiment by which you can show that it is possible to have boiling water and ice together in the same test tube.

30. A straight line is drawn on a piece of paper; part of the line is covered by a thick piece of plate glass. To an eye in most positions the line appears to be broken. How do you explain the fact? Illustrate your answer by a diagram.

31. What colour would a red rose appear if green light only fell upon it? Give any explanation you think necessary.

C. CHEMISTRY.

1. Three samples of water are given you, namely, rain-water, sea-water, and water from a well sunk in limestone rock. Describe what experiments you would make to distinguish the samples.

Describe, giving a sketch of the apparatus, how you would determine the weight of solid matter dissolved in a litre of one of these samples of water.

2. Describe carefully, giving a sketch of the apparatus, how you would prepare a flask full of hydrogen, in particular mentioning the precautions necessary to ensure that no air is present with the hydrogen.

Why is it that a balloon filled with hydrogen is able to rise through the air?

3. Powdered metallic copper is mixed with half its weight of sulphur, and some of the mixture is heated in a test tube. Describe what experiments you would make to show that before heating the copper and sulphur do not form a chemical compound, but that after heating they do.

4. How would you prove that oxygen is contained both in water and air?

5. Does lime dissolve when water is added to it? What is lime-water, and why is it transparent? Under what circumstances does it become milky?

6. State some of the properties of (1) Mercury, (2) Blue vitriol or Copper sulphate, (3) Carbon dioxide.

7. What is the composition of iron rust?

Describe the experiments you would make to prove the correctness of your statement.

8. Describe carefully how you would prepare a jar of dry nitrogen?

9. What is the chemical composition of charcoal?

Why is it that if you heat a piece of charcoal red-hot it glows very much more brightly when you blow on it?

Describe an experiment to prove the accuracy of your answer.

10. What are the composition and physical characteristics of lime and silica?

If you were given a mixture of powdered limestone and siliceous sand (*i.e.*, finely divided silica), how would you proceed to determine the weight of limestone contained in one kilogram of the mixture?

11. How would you make and collect hydrogen, and how would you show that it is lighter than air?

12. Describe what happens when a pellet of sodium is thrown into a beaker of water. State what becomes of the sodium, and how the water is affected by its disappearance.

13. Two beakers contain respectively powdered quicklime and powdered chalk. How is the condition and temperature of each altered when equal small quantities of water are poured upon them?

14. What is carbon dioxide? Mention some of its properties, for example, its relative weight, its solubility, any substances with which it can combine, and the nature of the combination.

15. Describe experiments to show (1) that when oxygen combines with hydrogen water is the result, and (2) that when water is decomposed oxygen and hydrogen are the products of the decomposition.

16. How is nitrogen distinguished from other gases? How would you prove that nitrogen exists in the atmosphere? Mention any compounds into which nitrogen enters.

17. State some of the chemical and physical properties of quicksilver. Why is it used in thermometers and barometers? What compounds does it form with other elements?

18. A piece of mineral is either quartz or marble; how would you decide which? What is the effect of heating (1) quartz, (2) marble, to a high temperature? How would you prove your statements?

19. Describe, illustrating your answer by a careful drawing, how you would prepare hydrogen.

Describe three experiments to illustrate the properties of this gas.

20. Describe experiments to show whether water is an element, a chemical compound, or a mixture.

21. Describe an experiment to show that carbon dioxide is produced when certain substances burn.

Give an example of a case where combustion is not accompanied by the formation of carbon dioxide.

22. What is meant by saying that matter is indestructible? Illustrate your answer by describing experiments to show the truth of the statement with reference (1) to change of state, and (2) to chemical change.

23. Why do we say that gunpowder is a mechanical mixture, and not a chemical compound? Give some reasons for the statement.

24. How can you prove that some portion of air disappears when iron "rusts" in it?

25. A cylinder of gas is given you to identify. It is found that the gas will neither burn itself nor allow a taper to burn in it; it has neither colour nor smell; it has no action on litmus. What gases are excluded by the results of these several tests? What gas will the gas contained in the cylinder probably be?

INDEX

ACCELERATION, 75, 77; measurement of, 78; unit of, 78; represented by lines, 79
Acid, 309
Adhesion, 11
Air, 259; composition of, 261; active part of, 257; compared with oxygen, 269; not a chemical compound, 270
Alkalies, 308
Angle, meaning of, 81; measurement of, 81; right, 82; unit, 82
Archimedes, Principle of, 65, 67
Area, 28; measurement of, 25
Argon, 262

BALANCE, principle of, 47; masses determined by means of, 49; weight of a body not determined by, 50
Barometer, 58—60
Base, 309
Bottle, relative density, 57
Buoyancy, 66
Burning, in oxygen, 265—270

CAMERA, pin-hole, 217; images produced by, 218
Candle, burning of, 17
Capacity, 31
Capacity for heat, 178—183; of water, 279; of different substances, 180—183
Carbon dioxide, preparation of, 297; properties of, 299; uses of, 299; occurrence of, 300
Carbon, forms of, 294; amorphous, 294
Centimetre, 23; cubic, 35
Chalk, 296; changes when heated, 296
Changes, chemical and physical, 253
Circle, 81
Cohesion, 8—10
Colour, 248; of transparent bodies, 248; of opaque bodies, 249; general considerations, 249
Columns, of water, balancing, 57; of different liquids, 58
Compass, Mariner's, 329
Component, 93
Compounds, 255
Conduction, 204; good and bad, 207
Convection, 208; currents, 210; definition of, 210; applications of heating by, 210

DAY, apparent solar, 74; mean solar, 74
Declination, magnetic, 319
Density, meaning of, 52; how compared, 54; standard of, 55; definition of, 55; relative, 55; of liquids, 55; maximum of water, 185—192; of water at different temperatures, 185; Hope's experiment on, 187, 190; changes in d. as water is cooled, 188
Diamond, 294
Dip, magnetic, 322; needle, 324; circle, 325; at different places, 325
Dispersion, 242; a consequence of unequal refraction, 242
Displacement, 61
Ductility, 4, 6

ELASTICITY, in solids, 2—4
Elements, 253
Energy, 145—154; definition, 145; kinetic, 145; potential, 145; forms of, 146; heat as a form of, 147—149; of radiant heat and light, 149, of electrification and electricity in motion, 150; of chemical action, 151; transformation of, 152; conservation of, 153
Ether, 215; waves, 216
Equator, magnetic, 327
Equilibrium, 136—141; stable 139; unstable, 139; neutral, 139; examples of, 140
Eudiometer, 283
Expansion, of solids, 156—159; of liquids, 157; of gases, 157; may indicate temperature, 162; anomalous e. of water, 186; of water as it freezes, 191

FOOT-POUND, 144
Forces, 88, 89; parallelogram of, 91; resolution of, 93; parallel, 107—114; principle of, 111; resultant of, 112; conditions for equilibrium of, 113
Friction, 123; limiting angle of, 124; on inclined plane, 125

GASES, characters of, 11, 12
Gram, 45
Graphite, 294
Gravitation, 41
Gravity, centre of, 131—141; experiments on, 131—3; definition of, 134; geometrical determination of, 135; relation to base of support, 138

HARDNESS, 4, 6; temporary and permanent, 289
Heat, effects of, 156—171; flow of, 173; capacity for, 174, 178—183; and temperature, 175; quantity of, 176; unit quantity of 180; transference of, 204—213
Hydrogen, preparation of, 277; properties of, 278—9

INDESTRUCTIBILITY of matter, 14—18; during evaporation, 14; during melting, 14; during solution, 14; in chemical change, 15—16
Illumination, due to overlapping of images, 219
Inertia, 87
Iron, 303; three kinds of, 303; oxides of, 304

KILOGRAM, 45

LACTOMETER, 64
Latent heat, 194; of water, 195; of steam, 196—8
Length, measurement of, 21
Lever, 99, 102; principle of work applied to, 101; classes of, 102; principle of, 105; first order, 103; second order, 104; third order, 105

Light, travels in straight lines, 216—217; intensity of, 219; reflection of, 222; regular reflection of, 224
Lime, 295; slaking of, 295
Liquids, 8; characters of, 6—11; flow of, 7, 9; surface of, 7; in communication, 7, 9; communicate pressure, 8, 10; can be separated into drops, 8, 10; definition of, 9; density of, 55
Lodestone, 313

MAGNET, 314; the earth as a, 328
Magnetism, primary laws of, 314, 318; terrestrial, 311—339
Mass, 40; is not weight, 40; measurement of, 43
Matter, 1; different kinds of, 2
Measure, square, 29
Melting point, 193; of wax, 192; of sulphur, 193; of ice, 193
Mercury, 305
Metals and non-metals, 255
Metre, 22; divisions of, 22
Mirror, formation of image by plane, 225; rotating, 226
Mixtures, 255; familiar examples of, 256
Moments, principle of, 99; definition of, 106
Momentum, 88
Motion, 75; first law of, 86; conversion of rectilinear into circular, 95

NITROGEN, preparation of, 260; properties of, 261

OXIDES, formation of, 269
Oxygen, preparation of, 262; the active constituent of air, 263; properties of, 265, 268; mixture, 264; compared with air, 269

PENDULUM, 73
Phosphorus, burning of, 18
Plane, 82; the inclined, 121—127; mechanical advantage of, 122, 123; definition of, 124; friction on, 125
Points, fixed, 166; freezing point, 166; boiling point, 167; effect of pressure on boiling, 168
Poles, Magnetic, 312; of the earth, 327
Pound, imperial, 44
Power, 144; horse, 144
Prism, 236; path of light through, 236; analysis of light by, 243
Pulley, simple, 117, 119; single fixed, 119; use of movable, 120; principle of work in, 120

RADIATION, 212, 213; reflection and refraction of, 215—239; travels in straight lines, 216
Recomposition, of white light, 246; by a second prism, 246; by a lens, 246; by colour-disc, 247
Reflection, laws of, 222—227; pin method of proving, 222; illustrated by mirror, 223; regular, 224; laws of regular, 225
Refraction, at plane surfaces, 228; by water, 228; pin method of proving laws, 229; phenomena caused by, 230; of light, 230; rules of, 231; through plate with parallel sides, 232; various effects of, 232; through a prism, 234; by a lens, 235, 237; of other forms of radiation, 239; is accompanied by dispersion, 242
Resultant, 92
Retardation, 78
Rigidity, 5
Rotation, 96; the earth's, 73
Rusting, of iron, 257

SALT, 309; common, 307; crystals of, 307; sodium chloride or, 308
Screw, 127; construction of, 127; principle of, 128; mechanical advantage, 129; pitch of, 128
Senses, 1
Shadows, 220; of a rod, 221
Silica, crystalline, 306; amorphous, 306
Solids, definition of, 5; characters of, 2—6; elasticity in, 2—4; determination of volume of irregular, 62; relative density of, 68; which float, 63; which sink, 63
Space, measurement of, 20
Specific gravity, 55
Spectroscope, 244
Spectrum, 245
State, change of, 12; sudden and gradual change of, 13

TELESCOPE, 238
Temperature, indicated by expansion, 162; of boiling water, 165; corresponds to water-level, 176
Tenacity, 4, 5
Thermometer, air, 158; differential, 158; choice of things to be used in, 162; why mercury is used for, 163; construction of, 163; graduation of, 164—168; scales, 169
Time, units of, 74; measurement of, 74

UMBRA, 221
Units, conversion of, 24

VELOCITY, 76; average, 76; unit of, 76; uniform linear, 76; represented by lines, 79; composition of, 80; parallelogram of, 80; angular, 83
Voltameter, 282
Volume, measurement of, 31; units of, 31; of a solid, 32; definition, 33; metric measures of, 34

WATER-LEVEL, 10
Water, 274; action of heated iron on, 274; sodium on, 275; chemical examination of, 275; of crystallisation, 280; is formed when hydrogen burns, 281; analysis of, 282; composition of by volume, 283; by mass, 284; solvent power of, 287; hard and soft, 288; distillation of, 289; mineral, 288
Weight, of a mass varies, 43
Work, 142; principle of, 107; definition, 143; measurement of, 143

YARD, 22

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